

***The kinematic, kinetic and blood
lactate profiles of continuous and
intra-set rest loading schemes***

Jamie Denton

B.S.R. (Auckland University of Technology)

B.A. (University of Auckland)

***A thesis submitted to the
Auckland University of Technology
in partial fulfilment of the degree of
Master of Health Science
January 2005***

TABLE OF CONTENTS

TABLE OF CONTENTS	I
LIST OF TABLES	IV
LIST OF FIGURES	V
LIST OF APPENDICIES.....	VI
LIST OF PUBLICATIONS / PRESENTATIONS FROM THIS THESIS	VII
ATTESTATION OF AUTHORSHIP	VIII
ACKNOWLEDGEMENTS	IX
DEDICATION.....	XI
GLOSSARY.....	XII
INTELLECTUAL PROPERTY RIGHTS	XVI
ABSTRACT.....	XVII
CHAPTER ONE: INTRODUCTION	1
INTRODUCTION	1
PURPOSE STATEMENT	4
AIMS.....	4
HYPOTHESES	4
SIGNIFICANCE OF THE THESIS	5
LIMITATIONS AND DELIMITATIONS	6
AUTHORSHIP CONTRIBUTION	7

NOTE TO READER.....	8
CHAPTER TWO: REST AND ITS INFLUENCE ON STRENGTH	
AND POWER ADAPTATION.....	9
INTRODUCTION	9
REST AND MAXIMAL STRENGTH TESTING.....	13
<i>Inter-repetition Rest Periods – Maximal Strength Testing.....</i>	<i>13</i>
<i>Inter-set Rest Periods – Maximal Strength Testing.....</i>	<i>13</i>
REST AND STRENGTH – HYPERTROPHY TRAINING.....	15
<i>Prescription</i>	<i>15</i>
<i>Research – Inter-set Rest Training</i>	<i>20</i>
REST AND STRENGTH – NEURONAL TRAINING.....	27
<i>Prescription</i>	<i>27</i>
<i>Research – Inter-set Rest Training</i>	<i>29</i>
<i>Research – Inter-repetition Rest Training.....</i>	<i>31</i>
REST AND POWER TESTING	36
<i>Inter-repetition Rest Periods – Power Testing</i>	<i>36</i>
<i>Inter-set Rest Periods – Power Testing</i>	<i>36</i>
REST AND POWER TRAINING	37
<i>Prescription</i>	<i>37</i>
<i>Research – Inter-set Rest Training</i>	<i>38</i>
<i>Research – Inter-repetition Rest Training.....</i>	<i>39</i>
INTRA-SET REST TRAINING	42
SUMMARY	44
CHAPTER THREE: THE KINEMATIC, KINETIC AND BLOOD	
LACTATE PROFILES OF CONTINUOUS AND INTRA-SET	
REST LOADING SCHEMES	47
PRELUDE.....	47
INTRODUCTION	48
METHODS	50
<i>Experimental Design.....</i>	<i>50</i>
<i>Subjects.....</i>	<i>50</i>

<i>Equipment</i>	51
<i>Experimental Testing</i>	53
<i>6RM Assessment</i>	53
<i>Loading Schemes</i>	54
<i>Blood Sampling</i>	55
<i>Data Analysis</i>	55
<i>Statistical Analysis</i>	56
RESULTS	57
DISCUSSION	62
PRACTICAL APPLICATIONS	67
ACKNOWLEDGEMENTS	69
CHAPTER FOUR: SUMMARY	70
SUMMARY	70
RECOMMENDATIONS	72
REFERENCES	74
APPENDICES	86

LIST OF TABLES

<i>TABLE 1:</i> TYPICAL LOADING PARAMETERS FOR MAXIMAL STRENGTH AND POWER TRAINING	12
<i>TABLE 2:</i> EFFECT OF DIFFERENT TRAINING PROTOCOLS AND REST DURATIONS ON HYPERTROPHY DEVELOPMENT	25
<i>TABLE 3:</i> EFFECT OF DIFFERENT TRAINING PROTOCOLS AND REST DURATIONS ON MAXIMAL STRENGTH DEVELOPMENT	34
<i>TABLE 4:</i> EFFECT OF DIFFERENT TRAINING PROTOCOLS AND REST DURATIONS ON MAXIMAL POWER DEVELOPMENT	41
<i>TABLE 5:</i> PARTICIPANT DESCRIPTIVE CHARACTERISTICS	51
<i>TABLE 6:</i> NUMBER OF REPETITIONS COMPLETED PER SET DURING THE CONTINUOUS AND INTRA-SET REST LOADING SCHEMES.....	57
<i>TABLE 7:</i> KINEMATIC AND KINETIC RESPONSES TO THE CONTINUOUS AND INTRA-SET REST LOADING SCHEMES.....	59

LIST OF FIGURES

<i>FIGURE 1: MODIFIED SMITH MACHINE</i>	51
<i>FIGURE 2: GRAPHICAL REPRESENTATION OF THE CONTINUOUS AND INTRA-SET REST LOADING SCHEMES</i>	55
<i>FIGURE 3: BLOOD LACTATE RESPONSES TO THE CONTINUOUS AND INTRA- SET REST LOADING SCHEMES</i>	62

LIST OF APPENDICIES

<i>APPENDIX 1: BLOOD LACTATE RESPONSES TO THE CONTINUOUS AND INTRA-SET REST LOADING SCHEMES</i>	87
<i>APPENDIX 2: PARTICIPANT INFORMATION SHEET</i>	88
<i>APPENDIX 3: PARTICIPANT CONSENT FORM</i>	90
<i>APPENDIX 4: ETHICS APPROVAL SHEET</i>	91
<i>APPENDIX 5: LABVIEW DATA COLLECTION PROGRAM (FRONT PANEL)</i>	92
<i>APPENDIX 6: LABVIEW DATA COLLECTION PROGRAM (BACK PANEL)</i>	93
<i>APPENDIX 7: LABVIEW DATA ANALYSIS PROGRAM (FRONT PANEL)</i>	95
<i>APPENDIX 8: MATHEMATICAL FORMULAE USED TO DERIVE KINEMATIC AND KINETIC VALUES FROM DISPLACEMENT DATA</i>	96

LIST OF PUBLICATIONS / PRESENTATIONS

FROM THIS THESIS

Denton, J. and Cronin, J.B. (2005). The kinematic, kinetic and blood lactate profiles of continuous and intra-set rest loading schemes (submitted to *Journal of Strength and Conditioning Research*).

Denton, J. and Cronin, J.B. (2005). Rest and its influence on strength and power adaptation (submitted to *Sports Medicine*).

Cronin, J.B. and Denton, J. The kinematic, kinetic and blood lactate profiles of continuous and intra-set rest loading schemes. *National Strength and Conditioning Association Conference*, Las Vegas, Nevada, July 2005.

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 nor material which to a substantial extent has been accepted for the qualification of any degree or diploma of a university or other institution of higher learning, except where due acknowledgment is made in the acknowledgments.

Signed.....

Date.....

ACKNOWLEDGEMENTS

I would like to express my gratitude to the many individuals who have contributed towards the completion of this thesis:

To Associate Professor John Cronin, my supervisor. Thank you for taking me on as a student, for your continued support and guidance throughout my undergraduate and postgraduate studies and for your invaluable assistance with this thesis. Your enthusiasm, experience and knowledge have been a major source of inspiration for the completion of my Masters degree. Thank you also for your high expectations and belief in me.

To Professor Will Hopkins. Thank you for all your help with all things meta-analytical and statistical. My apologies for the inclusion of P-values in this thesis.

To Peter (P-Dawg) Maulder. You have been a true friend through the thick and thin of the past two years. For this, I thank you. My post-graduate experience would not have been the same, or as enjoyable, without you.

To Dr. Andrew Kilding, Dr. Christian Cook, Blair Crewther and Justin Keogh. Thank you all for the much appreciated advice during the initial conception of this research.

To Shantelle Bliss, Jeremy Williams, Katrina van der Wende, Nicholas Stone, Ian Wilcock, Marcus Agnew and Joe McQuillan, my postgraduate colleagues. Thank you for your friendship, support and for making me laugh during the times of stress.

To Andrew, Marie, Ian, Jo and Emma, my family. Thank you for your support and belief in me throughout, without your love and patience I would have never completed this.

To Jordan McIntyre, Jonathon Peddie and Mark Morrison. Thank you for all your help during pilot testing.

To all the participants in this study. Thank you all for the time, dedication, effort and commitment that you put into each testing session.

I would also like to acknowledge the Auckland University of Technology for providing the funding needed to undertake this research.

Ethical approval for this research was provided by the Human Subject Ethics Committee of the Auckland University of Technology, 31st May 2004 – ethics approval number 04/27.

DEDICATION

This thesis is dedicated to my family for their constant love and support over the last 30 years. Above all it is dedicated to my parents and their endless belief in my abilities especially during the times when I did not believe in myself. Thank you for the opportunities and support that you have given me throughout my life.

GLOSSARY

The following terms are used throughout this thesis:

Concentric	A muscle contraction in which the active muscle or group of muscles shortens (Enoka, 2002).
Continuous training	The performance of resistance exercise in a steady manner (e.g. each repetition immediately follows the previous one until muscular fatigue or the end of the prescribed number of repetitions). Inter-set rest periods are prescribed between sets of continuous training.
Eccentric	A muscle contraction in which the active muscle or group of muscles lengthens (Enoka, 2002).
Hypertrophy	An increase in muscle mass due to training-induced increases in the cross-sectional area of the muscle fibres (Enoka, 2002).
Inter-repetition rest	The prescription of rest intervals between individual repetitions (Lawton, Cronin and Lindsell, In Press). Inter-repetition rest periods are most commonly associated with the assessment of strength and power.

Inter-set rest	The prescription of rest intervals between sets of exercise. Inter-set rest intervals are typically associated with continuous training schemes.
Intra-set rest training	The prescription of rest within the training set (Lawton et al., In Press). This involves breaking the training set into groups of repetitions, also known as clustering, and prescribing rest between these groups, or clusters, of repetitions.
Isokinetic	A contraction of a muscle or group of muscles that experiences varying levels of force but maintains a constant velocity (Cronin, 1996).
Isometric	A contraction of a muscle or group of muscles that achieves zero velocity (Cronin, 1996), also known as a static contraction and static strength.
Isoinertial	A contraction of a muscle or group of muscles that experiences varying levels of force and velocity but is performed against an external load with a constant inertia (Cronin, 1996). Resistance training is typically isoinertial in nature.

Kinematic	The examination of motion from a spatial and temporal perspective without reference to the forces causing the motion (Hamill and Knutzen, 1995).
Kinetic	The examination and description of the forces causing motion (Hamill and Knutzen, 1995).
Lactate	A salt or ester of lactic acid (Wilmore and Costill, 1999). Lactic acid is a metabolic by-product of anaerobic glycolysis.
Morphological	Pertaining to the form, structure or composition of the muscle.
Neuronal	Pertaining to the ability of the neural system to produce force through the activation and recruitment of motor units.
Power	The product of force and velocity. Power refers to the ability of the neuromuscular system to produce the greatest possible amount of force and velocity simultaneously, also known as speed-strength.

Repetition maximum (RM) The highest number of times that a particular mass can be successfully lifted (Knuttgen, 2003). For example, a 6RM load is the greatest load that can be successfully lifted six but not seven times.

Stretch-shortening cycle A muscle activation scheme in which an activated muscle first lengthens before it shortens (Enoka, 2002). This coupling of eccentric and concentric contractions is a common movement pattern during sporting performance and everyday activity.

INTELLECTUAL PROPERTY RIGHTS

This thesis may be utilised for the purpose of research or private study provided that due acknowledgment is made where appropriate and that the author's written permission is obtained before any material from the thesis is published.

I agree that the Auckland University of Technology Library may copy this thesis, in electronic or photocopied form, to supply the collection of other libraries on request from those libraries. I also agree that this thesis may be photocopied for supply to any person in accordance with the provision of Section 56 of the Copyright Act 1994.

ABSTRACT

The optimisation of strength and power through resistance training has been the source of debate amongst health professionals and researchers for many years. As resistance training involves the repeated activation and contraction of skeletal muscles, continuous training will ultimately result in a failure to sustain the training intensity especially when performing multiple sets and / or repetitions. Therefore the prescription of rest periods within the training session becomes an important consideration. Relatively short rest periods (60-90 seconds) have been traditionally used for the maximal strength adaptation involving increases in the cross-sectional area of the muscle, whereas longer rest periods (180-300 seconds) have traditionally been used for the maximal strength adaptation involving enhancement of neural function and maximal power adaptation. However, there is very little scientific evidence to support these current practices. In fact, the effect of different rest periods on maximal strength and power development has received very little research attention. Additionally, research that has been conducted in this area has been typified by a number of methodological inconsistencies, within and between studies, which confound scientific understanding.

Although traditionally resistance training has employed continuous training schemes with inter-set rest periods, intra-set rest training methods which distribute rest intervals between groups of repetitions have also been investigated. It has been theorised that the short rest periods within the training set allow partial resynthesis of the intramuscular phosphocreatine stores, potentially allowing an athlete to increase their training volume by training at

high intensities for longer durations, or performing additional repetitions (Berg, 2003). This is thought to lead to an increased exposure of the muscle to the kinematic and kinetic stimuli thought important for strength and power adaptation whilst minimising performance-inhibiting metabolic accumulation and substrate depletion. However, research into intra-set rest training schemes is still in its infancy, and many of the theories surrounding intra-set rest training are currently unsubstantiated. It is thought that examinations of the acute kinematic, kinetic and blood lactate profiles of continuous and intra-set rest training schemes may enhance scientific understanding regarding the efficacy of intra-set rest training.

The purpose of this study was to investigate and compare the acute kinematic, kinetic and blood lactate responses to continuous and intra-set rest loading schemes. Nine male subjects performed an isoinertial Smith machine bench press task (6RM load) with a continuous loading scheme (CONT), an intra-set rest loading scheme equated by total rest time, volume and load (ISRV) and an intra-set rest loading scheme equated by total rest time and load (ISRR). The order of the loading schemes was assigned in a block randomised order with a minimum of 48 hours recovery between each testing session. Attached to the bar of the Smith machine was a linear position transducer that measured vertical displacement with an accuracy of 0.01cm. Displacement data was sampled at 1000Hz and collected by a laptop computer running custom built data acquisition software. Finger prick blood lactate samples were taken from the non-dominant hand using sterile techniques at the following time points: pre-exercise (Pre), immediately post-exercise (P0), five (P5), fifteen (P15) and

thirty minutes (P30) post exercise. Blood glucose samples were taken pre-exercise only.

It was observed that manipulating the rest period, by increasing the frequency but decreasing the length of each rest period, did not significantly influence the kinematics and kinetics associated with resistance training, but did have an effect on the post-exercise blood lactate response when the load, rest duration and training volume was equated (ISRV). This finding may be of practical significance if fatigue is important in strength development or conversely if power training needs to be performed with minimal fatigue. It was also observed that increasing the frequency of the rest period enabled the subjects to perform a greater number of repetitions (ISRR), resulting in significantly greater kinematics, kinetics and blood lactate accumulation. It may be speculated, therefore, that ISRR training may offer a superior training stimulus for the development of maximal strength and hypertrophy than CONT training methods, as ISRR loading increased the exposure of the muscle to the kinematic, kinetic and metabolic stimuli thought important for the development of these qualities.

CHAPTER ONE: INTRODUCTION

INTRODUCTION

Muscular strength and power have been identified as important determinants of everyday activity and athletic success (Komi and Hakkinen, 1988). It is well known that the mechanical stimuli (e.g. time under tension, load, etc.) associated with resistance training are important for the development of maximal strength and power (Anderson and Kearney, 1982) however it has also been suggested that the optimal development of these muscular qualities may require the interaction of mechanical, hormonal (e.g. testosterone, human growth hormone, etc.) and metabolic (e.g. lactate, glycogen, etc.) stimuli (Enoka, 2002). Exercise induced secretion of anabolic (e.g. testosterone, growth hormone, etc.) and catabolic (e.g. cortisol) hormones are thought to regulate muscle tissue remodelling (Deschenes, Kraemer, Maresh and Crivello, 1991; Kraemer, 1992), whereas changes in the metabolic environment are thought to contribute to strength and power adaptation by enhancing motor unit recruitment (Carey Smith and Rutherford, 1995; Crewther, Cronin and Cook, In Press; Tesch, 1987). However, further research is required to properly understand the contribution of hormonal and metabolic stimuli to maximal strength and power development (Crewther et al., In Press).

Increases in the cross-sectional area of the muscle and / or enhanced neural function have been implicated in the development of maximal strength (Bloomer and Ives, 2000; Bosco, Cardinale and Tsarpela, 1999; Kraemer et al., 2002). Typically loads of 60-70%1RM have been employed for increasing the

cross-sectional area of the muscle, as these loads are thought to subject the muscle to high tensions for substantial durations, whereas training programmes designed to enhance neural function are typified by loads of 85-100%1RM, as these loads are thought to maximally activate the neural system, especially the fast twitch α motor units (Tesch, Ploutz-Snyder, Ystrom, Castro and Dudley, 1998). Training programmes designed to increase muscular power, on the other hand, are typified by loads of approximately 45%1RM as the rapid acceleration of these loads are thought best to optimise the contribution of force and velocity, the components of power.

Given the nature of strength and power training, which involves the repeated activation and contraction of skeletal muscles, there is no doubt that continuous training will ultimately result in a failure to sustain the training intensity (Nigg, MacIntosh and Mester, 2000) especially when performing multiple sets and / or repetitions. Therefore, rest periods become an important consideration when prescribing resistance exercise. Typically, hypertrophy training has used relatively short rest periods (60-90 seconds), whereas neuronal strength and power training are typified by relatively long rest periods (180-300 seconds). However, little is known about the effect that different rest periods may have on the development of maximal strength and power, if any. Research in this area is typified by a wide spectrum of loading parameters that include differences in: (a) volume; (b) intensity (%1RM); (c) total work output; (d) tempo of concentric-eccentric contractions; (e) frequency; (f) rest time; and, (g) type of contractions. Further confounding our understanding in this area are the modes of dynamometry (isometric, isokinetic and isoinertial) used and the

variety of strength and power measures reported. Finally, many different muscle groups (uniarticular vs. multiarticular, small vs. large, fusiform vs. pennate, etc.) have been studied in subjects ranging from novice or untrained to experienced trainers and / or elite sports men and women. Making definitive conclusions regarding the effect of rest becomes difficult given these circumstances. In fact, it is difficult to find any empirical evidence to justify the recommendations regarding rest that are disseminated to students, athletes, coaches and health professionals through textbooks, coaching manuals and review articles.

While continuous training schemes with inter-set rest periods have been traditionally prescribed, intra-set rest training schemes which distribute the rest within the training set have also been investigated as an alternative method for prescribing resistance exercise (Lawton, Cronin, Drinkwater, Lindsell and Pyne, 2004). It has been theorised that intra-set rest loading may increase the exposure of the muscle to the kinematic and kinetic stimuli thought important for the development of maximal strength and power whilst simultaneously minimising the performance-inhibiting effects of metabolic accumulation and substrate depletion. However, research into intra-set rest training is still in its infancy, so many of the theories of intra-set rest training are currently unsubstantiated. Previous research that has investigated intra-set rest training has been limited to examining the power outputs associated with this type of training. To our knowledge, no previous research has compared the kinematic, kinetic and blood lactate profiles of continuous and intra-set rest training. It is

thought that such an analysis would improve scientific understanding of the training effects of such schemes.

PURPOSE STATEMENT

The purpose of this thesis is to provide an overview of knowledge regarding the effect of rest on maximal strength and power development and to investigate the acute kinematic, kinetic and blood lactate responses of the human body to continuous and intra-set rest loading schemes. Firstly, the literature concerning rest and its influence on strength and power adaptation will be critically reviewed and discussed (see Chapter Two). Secondly, the kinematic, kinetic and blood lactate profiles of continuous and intra-set rest loading schemes will be examined and discussed (see Chapter Three).

AIMS

The primary aim of this study is to determine whether the acute kinematic, kinetic and blood lactate profiles of continuous and intra-set rest loading schemes significantly differ. A secondary aim of this study is to critically review the literature in this area, noting the effects of different rest periods on the development of maximal strength and power through resistance training.

HYPOTHESES

It is hypothesised that the intra-set rest loading schemes will produce significantly greater kinematic and kinetic values as compared to the

continuous scheme even though the load is equated. As a result of the greater kinematics and kinetics it is also hypothesised that the ISRR loading scheme will result in significantly greater blood lactate than the other schemes.

SIGNIFICANCE OF THE THESIS

Continuous training, with inter-set rest periods, is the most commonly prescribed training method for resistance exercise. However, to our knowledge, there is currently no empirical evidence regarding the optimal inter-set rest period length for the development of maximal strength and power. Additionally, there is no conclusive scientific evidence that continuous schemes with inter-set rest periods are optimal for the development of these strength qualities. Alternative methods of prescribing rest and exercise, including inter-repetition and intra-set rest training schemes, have also received some research interest. Intra-set rest training methods have been theorised to increase the exposure of the muscle to the kinematic and kinetic stimuli thought important for the development of maximal strength and power whilst minimising the performance inhibiting effects of metabolic accumulation and substrate depletion. However, research in this area is still in its infancy and these theories have not been properly investigated. This research will investigate the acute kinematic, kinetic and blood lactate responses to continuous and intra-set rest loading schemes and may therefore provide information by which informed decisions regarding continuous and intra-set rest loading schemes can be made. It may also provide the framework for further research into the efficacy of intra-set rest loading methods for developing maximal strength and power.

LIMITATIONS AND DELIMITATIONS

The authors note and acknowledge the following limitations and delimitations within this research project:

1. Due to the subject inclusion criteria (males with a minimum of 12 months previous resistance training experience) the findings of this research may be confined to this population.
2. Due to a combination of the subject inclusion criteria, financial constraints and the inclusion of blood sampling limiting the number of subjects willing to participate, the sample size used within this research was relatively small which may have limited our ability to detect statistical significance for smaller effect sizes.
3. As this research was performed as an acute cross-sectional study, these findings do not allow inferences to be made regarding the kinematic, kinetic and blood lactate responses to longitudinal training with these schemes.
4. All testing sessions were performed in a laboratory setting using a Smith machine. The Smith machine was chosen for safety, easy instrumentation, availability and subject familiarity.
5. This research investigated a bench press exercise performed with explosive concentric contractions. Therefore the findings of this study may be limited to this exercise and training technique.
6. The process for obtaining the kinetic data involved differentiating the kinematic data, which in turn had been differentiated from the vertical displacement or positional data. Although the displacement data was filtered prior to differentiation, this double-differentiation process has

inherent problems with noise, which may have affected the accuracy of the kinetic data.

7. The loading parameters employed were designed to replicate a typical training session for the development of upper-body power. However, the loading parameters and ballistic training techniques employed may have differed from those performed in practice. Additionally, some of the subjects who participated in this study may have only a limited experience with such loading parameters and training techniques.
8. During data analysis, individual kinematic, kinetic and blood lactate data were pooled to provide group means for each loading scheme. Therefore individual responses are not reflected within the final data.
9. The metabolic profiles were limited to blood lactate responses which do not reflect the wide variety of acute changes within the metabolic environment during resistance training. The metabolic profiles were limited in this way due to financial and ethical considerations.

AUTHORSHIP CONTRIBUTION

The contributions of the authors to the literature review and experimental paper submitted within this thesis are as follows:

1. Literature review: Rest and its influence on strength and power adaptation:

Denton, J. (90%), Cronin, J.B. (10%).

2. Experimental paper: The kinematic, kinetic and blood lactate profiles of continuous and intra-set rest loading:

Denton, J. (90%), Cronin, J.B. (10%).

NOTE TO READER

This thesis is presented as two main sections, the first being a literature review (Chapter Two) regarding the influence of rest on maximal strength and power development, and the second being the experimental section (Chapter Three), which have been written specifically for publication. Some of the information in this thesis may appear repetitive due to this format. Regardless, this thesis fulfils the AUT Master of Health Science guidelines for thesis submission.

CHAPTER TWO: REST AND ITS INFLUENCE ON STRENGTH AND POWER ADAPTATION

INTRODUCTION

It is well known that the mechanical stimuli associated with resistance training are important determinants of strength and power adaptation (Anderson and Kearney, 1982). For example, high forces and time under tension are thought critical for the strength adaptation involving increases in the cross-sectional area of muscle (Enoka, 2002; McDonagh and Davies, 1984; Moss, Refsnes, Abildgaard, Nicolaysen and Jensen, 1997). The loading parameters for such training can be observed in Table 1 and are those typically used by body builders. The tempo, number of repetitions and / or sets, and the brevity of the rest periods result in the muscle being subjected to high tensions for substantial durations, which is thought to result in an increased rate of protein breakdown, or muscle damage, during training. According to the “break down build up” theory of tissue remodelling, protein breakdown during training results in an increased protein synthesis, decreased protein degradation or a combination of the two (Kraemer et al., 2002) during recovery, ultimately resulting in an increase in muscle size (hypertrophy). It is thought that hypertrophy loading schemes result in greater protein breakdown, hence greater hypertrophic adaptation, than neuronal maximal strength and power training methods.

Neuronal maximal strength training (see Table 1) involves lifting near maximal loads (1-4RM) as explosively as possible. This type of loading is used by power-lifters and weight-lifters who need to increase their strength whilst

minimising increases in cross-sectional area so that they can stay in certain competitive weight categories. The high load forces and subsequent high muscle tensions associated with such loading are thought to maximally activate the nervous system, in particular the high threshold fast twitch α motor units (Tesch et al., 1998). Associated with this type of loading is minimal time under tension and subsequent protein degradation, hence minimal hypertrophy (Villani, 1987).

Many different exercises and loading parameters are thought to optimise power development. For example, the use of Olympic lifts and / or the lifting of loads similar to the neuronal training methods described previously are used for power development. Since power is the product of force and velocity, it is thought that techniques and loads that optimise the contribution of these two mechanical stimuli will optimise power development. Hence ballistic techniques (projection of the athlete's body e.g. plyometrics, the athlete's body and a bar e.g. jump squat, or of the bar e.g. bench press throw) are thought best to maximise power development (Newton, Kraemer, Hakkinen, Humphries and Murphy, 1996; Newton et al., 1997). Typical ballistic loading parameters normally associated with power development training can be observed in Table 1.

While there is no doubt that the development of strength and power are determined by the interaction of various mechanical stimuli, less is known about the effect of different rest periods on these variables. Previous literature directly examining the effect of rest on the kinematics and kinetics associated

with resistance training is limited. In fact, it is difficult to find research based evidence that has shaped our present guidelines concerning the ideal rest period for certain loading parameters. Further confounding our understanding is a number of methodological issues. For example, the vast majority of research has been relatively short in duration (8-12 weeks) and therefore the application of these findings to long-term training is questionable as the influence of neural and morphological mechanisms change with training duration (Moritani, 1992). Research in this area is also typified by a wide spectrum of loading parameters that include differences in: (a) volume; (b) intensity (%1RM); (c) total work output; (d) tempo of concentric-eccentric contractions; (e) frequency; (f) rest time; and, (g) type of contractions. The modes of dynamometry (isometric, isokinetic and isoinertial) used and the variety of strength and power measures reported also limit our understanding in this area. Finally, many different muscle groups (uniarticular vs. multiarticular, small vs. large, fusiform vs. pennate, etc.) have been studied in subjects ranging from novice or untrained to experienced trainers and / or elite sports men and women. Making definitive conclusions regarding the effect of rest becomes somewhat difficult given these circumstances.

For the most part the effect of rest has been studied in terms of repeated maximal strength (1RM) and power (height or distance jumped) testing with little attention given to the effect of rest on the kinematics and kinetics associated with strength and power training and adaptation. In turn this makes it difficult to draw any inferences about the efficacy of different rest periods on

the mechanical variables discussed previously. The reader needs to be cognizant of these limitations.

Table 1: Typical loading parameters for maximal strength and power training

Parameter	Maximal Strength		Power
	Hypertrophy	Neuronal	
Intensity	60-70% 1RM	85-100% 1RM	45% 1RM
Sets	3-6	2-5	3-6
Lifting tempo	1-2 s	1-2 s	<1 s
Inter-set rest	30-90 s	180-300 s	180-300 s

From: Bloomer and Ives, 2000; Komi and Hakkinen, 1988; Kraemer et al., 2002; MacDougall, 1992; Mazzetti et al., 2000; McDonagh and Davies, 1984; Newton et al., 1996; Stone et al., 1998; Zatsiorsky, 1995

REST AND MAXIMAL STRENGTH TESTING

Inter-repetition Rest Periods – Maximal Strength Testing

Researchers investigating the acute effect of different rest intervals on maximal strength have observed that short rest periods do not significantly affect repeated 1RM attempts. Weir et al. (1994) and Matuszak et al. (2003) examined the effect of different rest intervals on the ability to perform repeated 1RM lifts (bench press and back squat respectively) in trained male subjects. While both studies employed rest intervals of 60, 180 and 300 seconds, Weir et al. (1994) also included an additional 600 second rest interval. The authors, in both studies, reported no significant differences in the ability to successfully repeat a 1RM lift after the different rest intervals. It has therefore been suggested that rest intervals as short as 60 seconds do not appear to significantly impair the ability to reproduce single maximal effort contractions (Matuszak et al., 2003).

Inter-set Rest Periods – Maximal Strength Testing

When performing multiple repetitions, it has been observed that short rest intervals can significantly decrease an athlete's ability to maintain the prescribed training intensity. For example, Kraemer (1997) observed significant reductions in the number of repetitions performed, during three sets of exercise with a 10RM load, when a 60 second rest interval was prescribed between sets (30%). In contrast, when the rest intervals were increased to 180 seconds, no significant differences were observed in the number of repetitions performed per set. Kraemer (1997) therefore suggested that the length of the rest interval

may be a crucial variable in the determination of lifting performance with multiple sets.

Larson and Potteiger (1997) investigated the efficacy of using three different rest protocols: 1) 180 seconds inter-set rest; 2) a 1:3 work to rest ratio; and, 3) attaining a post-exercise heart rate equal to 60% of the age-predicted maximum heart rate. The rest times for the 1:3 work to rest ratio was 234.0 ± 10.8 , 163.0 ± 11.2 , 125.0 ± 8.4 , and 102.0 ± 8.5 seconds for sets 1, 2, 3 and 4 respectively. The authors observed no significant differences between rest protocols in the ability to successfully repeat multiple sets, suggesting that each of these rest protocols were effective. However, as the subjects were recreationally trained males, these findings may be limited to this specific population.

Woods et al. (2004) reported no significant differences between three different rest intervals (60, 120 and 180 seconds) on perceived exertion during an isoinertial knee extension exercise. Thirty trained male ($n = 15$) and female ($n = 15$) subjects were asked to perform three sets of 10 repetitions (70%1RM) and report their perceived exertion per repetition using the Borg CR-10 scale. During each set the subject was blinded to the load that they were lifting. While significant increases in perceived exertion were observed within each protocol, there were no significant differences between protocols. However it was observed that during the third set of exercise fewer subjects (50%) were able to complete the prescribed number of repetitions when the prescribed rest period was short (60 seconds) compared to the groups with the longer rest periods (30%). It therefore seems that the length of the rest interval may not

significantly affect the perceived exertion associated with the lifting task, but may limit the number of repetitions performed during multiple sets of resistance exercise if the rest is of short duration (~ 60 s). However, care must be given in assuming the findings from such acute studies would be similar to those associated with longitudinal training studies.

REST AND STRENGTH – HYPERTROPHY TRAINING

Prescription

It is commonly recommended that rest intervals of between 30 and 90 seconds are optimal for the development of hypertrophy. These recommendations are disseminated to students, strength coaches and other health and / or sport professionals through sources such as textbooks, coaching manuals and review articles. However, adopting such a practice would seem problematic if one was to critique the literature in this area. A number of these sources have not referenced any supporting scientific research to justify their rest period recommendations (Dowson, 1996; Zatsiorsky, 1995). Therefore, as no reference is made, it is impossible to critically evaluate the scientific validity of their claim. For example, Zatsiorsky (1995) recommended using between 60 and 120 seconds inter-set rest periods, but does not cite any scientific evidence to justify these claims.

Some authors have based their recommendations on references that have simply reported the typical rest intervals used by bodybuilders. For example, one of Baechle and Earle's (2000) recommendations, for the use of between 30

and 60 seconds rest, was supported with a reference to Tesch's (1992) observation that these rest periods are commonly used by competitive bodybuilders. Similarly, Poliquin (1991) and Plisk (2001) reported the typical rest intervals used by bodybuilders, but did not discuss the efficacy of training with such rest periods. While anecdotally it would appear that short rest intervals may stimulate muscular hypertrophy, as bodybuilders exhibit large degrees of muscular hypertrophy and use these rest intervals, there is currently no conclusive empirical evidence to suggest that these rest intervals are optimal. It may be that the large volume of work and / or time under tension per muscle group are the key stimuli to hypertrophic adaptation for body builders, and whether the rest duration is 60 or 180 seconds might be relatively unimportant. Therefore it would appear fallacious to base recommendations on such anecdotal evidence, especially as strength endurance training, which employs similarly short rest periods, does not result in substantial muscular hypertrophy (Kraemer et al., 2002).

Other authors have cited increases in the accumulation of circulating metabolites as empirical evidence to support their recommendations for brief rest durations. For example, Wilson's (1999) recommendation of integrating a combination of short (60 seconds) and longer (180 seconds) rest intervals into the training week was based on Schott et al.'s (1995) investigation of the metabolic profiles of short and long isometric contractions. Short, intermittent isometric contractions (four sets of 10 contractions of three seconds duration with two seconds inter-repetition rest and 120 seconds inter-set rest) were compared with long, sustained isometric contractions (four contractions of 30

seconds duration with 60 seconds inter-repetition rest), the intensity was equated between protocols at 70% of the individual's maximum voluntary contraction. Subjects trained three times per week for 14 weeks, and trained their right leg with the short, intermittent contractions and their left leg with the long, sustained contractions. The largest metabolic accumulations, and greater increases in hypertrophy, were associated with the longer isometric protocol. The authors therefore concluded that hypertrophic development may be related to the degree of fatigue achieved within the musculature. However, the relation of these findings to the optimal rest interval for hypertrophy development may be limited, as the mode of dynamometry employed in this study (isometric) does not accurately describe the movement patterns prevalent in typical hypertrophy training schemes (isoinertial).

Baechle and Earle (2000) based one of their recommendations, for the use of between 30 and 90 seconds rest, on Kraemer et al.'s (1987) observation of significantly lower blood lactate accumulation in bodybuilders, compared to weight-lifters, during resistance exercise with very short rest periods (10 seconds). However, while effective bodybuilding programs tend to be more muscle fatiguing (Lambert and Flynn, 2002; Rooney, Herbert and Balnave, 1994), and there has been speculation that the metabolic stimulus may be important for muscle growth, scientific understanding in this area is still speculative (Crewther, 2004). Therefore, while a clear understanding of the importance of the metabolic stimulus in the development of hypertrophy remains elusive, it would appear misleading to base recommendations for

optimal rest duration on the metabolic profiles of different resistance training techniques.

Similarly, a number of recommendations regarding rest duration have been based on the hormonal profile of different resistance training protocols. For example, Kraemer et al. (2002; 2004) based their recommendations for short (60 to 120 seconds) inter-set rest periods on the results of an earlier study (1990), which investigated the hormonal (testosterone, growth hormone, somatomedin) responses to typical strength and hypertrophy training protocols. While this study was primarily concerned with the differences between typical strength and hypertrophy training protocols, interestingly Kraemer et al. (1990) also employed additional protocols to control for rest and load. Therefore, two of the protocols used involved hypertrophy schemes of equal load and volume but different rest intervals (60 and 180 seconds rest). Kraemer et al. (1990) reported significantly larger testosterone (an anabolic hormone thought to directly affect skeletal muscle growth) responses during and five minutes post-exercise when the rest interval was reduced to 60 seconds. However, no significant differences in testosterone concentrations between the two rest periods were found when area under the curve comparisons were made. Therefore although there may have been larger fluxes of circulating testosterone at specific time points, the average testosterone volume did not differ significantly between the two rest intervals. The area under the curve comparisons also indicated that the somatomedin (also thought important for tissue growth) concentrations were not significantly affected by changing the rest interval either. On the other hand, reducing the rest interval did have a

significant effect on the accumulation of growth hormone. The 60 second rest protocol elicited larger increases in circulating growth hormone than the 180 second rest protocol. However, it has been suggested that the role of growth hormone in hypertrophic adaptation may be minimal. Rennie (2003) argued that growth hormone may be unlikely to have a large influence on the development of muscular hypertrophy as female athletes have been shown to secrete larger amounts of growth hormone at the same exercise intensity as their male counterparts (Pritzlaff-Roy et al., 2002) but males still demonstrate greater muscle mass and strength gains than females. Additionally, growth hormone secretion tends to be greater with moderate dynamic exercise (e.g. cycling at 75% of an athletes maximum heart rate) than resistance exercise (Consitt, Copeland and Tremblay, 2002), while this dynamic exercise has not been shown to significantly increase muscle cross-sectional area.

It is difficult to find any conclusive empirical evidence to support the recommendations disseminated by most authors and researchers regarding the optimal inter-set rest interval to maximise hypertrophic gain. These recommendations appear to be based on anecdotal evidence, or inferences drawn from the literature despite the inconsistencies and limitations discussed earlier. Thus, it is our opinion that a large number of the current recommendations are based on nothing more substantial than anecdotal evidence and observations of the typical rest periods used by competitive bodybuilders. It is important that further research be conducted investigating the effect of different rest intervals on the development of hypertrophy.

Research – Inter-set Rest Training

In terms of training studies, to our knowledge, no previous research exists that has directly investigated the effect of different inter-set rest periods on the development of hypertrophy in trained or untrained subjects. Typically, research investigating the development of hypertrophy, which reported the rest periods used, have employed protocols typified by rest periods of equal length (see Table 2). It would appear from Table 2 that those studies that have used 180 seconds inter-set rest resulted in an average of 4% hypertrophic increase in the upper body and a 10% increase in the lower body (Brandenburg and Docherty, 2002; Chestnut and Docherty, 1999; Ostrowski, Wilson, Weatherby, Murphy and Lyttle, 1997; Young and Bilby, 1993), while studies that used 120 seconds inter-set rest resulted in an average increase of 10% in the upper body and 5% in the lower body (Brown, McCartney and Sale, 1990; Calder, Chilibeck, Webber and Sale, 1994; Chestnut and Docherty, 1999). However, it is important to note that the methodological inconsistencies within and between these studies, and discussed previously, make it impossible to conclusively identify the effect that the rest duration had on the extent of the hypertrophic gain.

Two papers that have included different rest periods in their research design have also manipulated the loading parameters (Campos et al., 2002; Chestnut and Docherty, 1999). Hence any differences in hypertrophic gain may be attributed to the kinematics and kinetics associated with the load rather than the rest period. Furthermore, untrained subjects were used in both these studies.

However, despite these limitations, these papers would seem to offer some insight into the effect of rest on the development of strength and hypertrophy.

Chestnut et al. (1999) investigated the effect of 10 weeks training with two different training schemes on the development of maximal strength and hypertrophy in 24 untrained male subjects. Participants were randomly assigned to a neuronal loading group (six sets of 4RM with 180 seconds rest) or a hypertrophy loading group (three sets of 10RM with 120 seconds rest). Subjects performed a number of primary exercises (e.g. triceps bench press, standing bicep curl, etc.) targeting the elbow flexors and extensors, and supplementary exercises (e.g. bench press, bench pull, etc.) three times per week. The supplementary exercises were performed with the same loads as the primary exercises but with a reduced number of sets (two sets of 4RM vs. one set of 10RM). The training volume was equated in accordance with O'Hagan et al.'s (1995) calculations (repetitions x sets x %1RM). Significant differences were observed within groups for the hypertrophy (MRI and muscle girths) and strength (isoinertial 1RM of the elbow flexors and extensors) measures but the magnitude of these increases were not significantly different between groups. Chestnut et al. (1999) therefore suggested that for relatively untrained male subjects a 10-week training program of either 4RM or 10RM with rest periods of 180 or 120 seconds will produce similar improvements in strength and hypertrophy. However, as acknowledged by the authors, this lack of training specificity is unlikely to hold for previously resistance trained subjects.

Campos et al. (2002) investigated the effect of eight weeks resistance training with three different equi-volume protocols in 32 untrained male subjects. Subjects were randomly assigned to perform either four sets of 3-5RM with 180 seconds inter-set rest, three sets of 9-11RM with 120 seconds inter-set rest or two sets of 20-28RM with 60 seconds inter-set rest. The number of sets and repetitions were equated using the calculations described previously. The authors reported significant differences in the strength improvements observed between groups with the neuronal (3-5RM, 180 seconds rest) group exhibiting significantly greater increases in leg press and squat 1RM than the hypertrophy (9-11RM, 120 seconds rest) and strength endurance (20-28RM, 60 seconds rest) groups (leg press 1RM = 61% vs. 36% vs. 32% respectively). These observations contradict Chestnut et al.'s (1999) suggestion that neuronal and hypertrophy loading schemes, and their typical rest periods, elicit similar strength gains in untrained male subjects. In terms of hypertrophy, however, Campos et al. (2002) reported observing significant hypertrophic effects, as measured through muscle biopsies, only within the neuronal and hypertrophy groups and that the magnitude of these increases were not significantly different between groups. This supports Chestnut et al.'s (1999) suggestion that neuronal and hypertrophy loading schemes, and the rest periods typical of such loading schemes, may elicit similar increases in hypertrophy in previously untrained male subjects. It is difficult to identify if the different rest periods had any effect on the strength or hypertrophy increases within each group, as the authors failed to report any kinematic or kinetic data. It may therefore be that differences in the kinematics and / or kinetics associated with the different

loads, and not the rest period, that may be the cause of the strength and hypertrophy increases observed.

Robinson et al. (1995) investigated the effects of three different rest intervals on the development of maximal strength and hypertrophy in 33 moderately trained male subjects. The subjects were randomly assigned to one of three different rest intervals (180, 90 and 30 seconds), and performed five weeks of equi-volume training (five sets of 10RM) with their allocated rest interval. Multiple exercises were performed (e.g. squat, bench press, etc.) to simulate a typical training program with additional exercises (three sets of 10RM) targeting smaller muscle groups performed also to supplement the program. Robinson et al. (1995) reported significantly greater increases in isoinertial 1RM squats in the subjects who had rested for 180 seconds (6.8%) compared to the subjects who rested for 30 seconds (2.3%). However, it has recently been argued (Carpinelli, Otto and Winett, 2004) that Robinson et al.'s (1995) failure to indicate whether the differences observed between the 180 second rest group (6.8%) and the 90 second rest group (5.8%), or between the 90 second rest group and the 30 second rest group, were statistically significant does not support Robinson et al.'s (1995) claim that there is a rest-period continuum for strength development. Interestingly, despite employing typical hypertrophy loading parameters Robinson et al. (1995) reported no significant differences between groups in their hypertrophy measures. Additionally, although Robinson et al. (1995) observed significant increases in strength, the loading parameters (10RM) did not accurately reflect typical loading parameters (1-

4RM) for the development of maximal strength, therefore the relation of these results to neuronal strength development training may be questionable.

Table 2: Effect of different training protocols and rest durations on hypertrophy development

Author(s)	Subjects	Training Frequency and Duration	Protocols	Tempo	Rest (s)	Measures	Results					
							Strength % Change			Hypertrophy % Change		
							P ≤			P ≤		
Brandenburg & Docherty (2002)	18 Male T	9 weeks (2 x weeks 1-2) (3 x weeks 2-9)	4 x 10RM	2 s ↑	180	MRI	Elbow Flex	11	.05 *	Elbow Flex	3.1	— *
							Elbow Ext.	15	.05 *	Elbow Ext.	1.7	— *
			Extra ECC load (3 x 10RM CON) (3 x 10 x 110% ECC)	2 s ↑	180	Elbow Flex	9	.05 *	Elbow Flex	-0.3	— *	
						Elbow Ext.	24	.05 **	Elbow Ext.	1.7	— *	
Brown et al. (1990)	14 old Male U	3 x 12 weeks	Progressive up to 2 x 70-90%1RM	N/A	120	CT Scans 1RM	Elbow Flex	48.4	.001 *	Elbow Flex	17.4	.001 *
							Leg Press	~20.3	.001 *	Knee Flex	4.4	.01 *
							BPress	~25.4	.001 *	Knee Ext.	9.9	.01 *
Calder et al. (1994)	30 Female U	10 weeks (W = 2 x week) (S = 2xUO +2xLOxWeek)	Whole Body Programme Upper (5 x 6-10RM) Lower (5 x 10-12RM)	N/A	120	Densito. 1RM	Elbow Flex	54	.001 *	Arm	10	.05 *
							BPress	33	.001 *	Trunk	3.4	— *
							Leg Press	21	.001 *	Leg	4.9	.05 *
			Split Programme Upper (5 x 6-10RM) Lower (5 x 10-12RM)	N/A	120	Elbow Flex	69	.001 *	Arm	9.2	.05 *	
						BPress	32	.001 *	Trunk	2.7	— *	
						Leg Press	22	.001 *	Leg	1.7	— *	
Campos et al. (2002)	32 Male U	8 weeks (2 x weeks 1-4) (3 x weeks 5-8)	Low rep (4 x 3-5RM)	N/A	180	Biopsies 1RM	Leg Press	~61.3	.05 **	Type I	12.4	.05 *
							Squat	~118	.05 **	Type IIA	22.9	.05 *
							Leg Ext.	~50	.05 **	Type IIB	25.3	.05 *
			Inter rep (3 x 9-12RM)	N/A	120	Leg Press	~41.4	.05 **	Type I	13.1	.05 *	
						Squat	~91	.05 **	Type IIA	16.3	.05 *	
						Leg Ext.	~45	.05 *	Type IIB	27.3	.05 *	
			High rep (2 x 20-28RM)	N/A	60	Leg Press	~27.6	.05 *	Type I	10.4	— *	
						Squat	~72.7	.05 *	Type IIA	8.0	— *	
						Leg Ext.	~55.6	.05 *	Type IIB	13.5	— *	
Chestnut & Docherty (1999)	24 Male U	3 x 10 weeks	6 x 4RM	N/A	180	MRI Anthro.	Elbow Flex	13.7	.05 *	Mid	9.28	.05 *
							Elbow Ext.	16.9	.05 *	Dist	5.15	.05 *
			3 x 10RM	N/A	120	Elbow Flex	10.6	.05 *	Mid	9.09	.05 *	
						Elbow Ext.	18.1	.05 *	Dist	6.32	.05 *	

Ostrowski et al. (1997)	35 Male T	4 x 10 weeks	High Volume (9 x 12RM x weeks 1-4) (7RM x weeks 5-7) (9RM x weeks 8-10)	N/A	180	Ultrasound 1RM	Squat	11.6	.05 *	RcFem	6.77	.05 *				
			Moderate Volume (6 x 12RM x weeks 1-4) (7RM x weeks 5-7) (9RM x weeks 8-10)	N/A	180		BPress	1.93	.05 *	Tricep	2.27	.05 *				
							Squat	5.48	.05 *	RcFem	5.0	.05 *				
			Low Volume (3 x 12RM x weeks 1-4) (7RM x weeks 5-7) (9RM x weeks 8-10)	N/A	180		BPress	4.96	.05 *	Tricep	4.65	.05 *				
							Squat	7.46	.05 *	RcFem	13.1	.05 *				
							BPress	4.01	.05 *	Tricep	4.76	.05 *				
			Robinson et al. (1995)	33 Male T	4 x 5 weeks		Inter rep (5 x 10RM)	N/A	180	1RM	Squat	7.3	.05 **†	Body Mass	0.6	-**†
							Inter rep (5 x 10RM)	N/A	90		Skinfolds	-2.9	-**†			
											Squat	5.8	.05 *	Body Mass	0.3	-**†
Inter rep (5 x 10RM)	N/A	30				Skinfolds	-6.8	-**†								
						Squat	2.4	.05 *	Body Mass		-0.7	-**†				
						Skinfolds	-5.2	-**†								
Young & Bilby (1993)	18 Male U	3 x 7 ½ weeks	Explosive (4 x 8-12RM)	EXPL	180	Ultrasound Anthro.	Squat	19.9	.01 *	VI	24.4	.001 *				
			Slow (4 x 8-12RM)	N/A	180		RcFem	1.4	.001 *							
							Squat	22.0	.01 *	VI	21.0	.001 *				
							RcFem	1.5	.001 *							

NOTE: *, within group contrast; †, between group contrast; Anthro., anthropometric; BPress, bench press; CON, concentric; CT, computer topography; densito., densitometry; dist, distal; ECC, eccentric; EXPL, explosive; Ext., extensors / extension; Flex, flexors / flexion; mid, midpoint; LO, Lower body only; MRI, magnetic resonance imaging; RcFem, rectus femoris; RM, repetition maximum; s, seconds; S, Split program; T, trained; U, untrained; UO, Upper body only; VI, vastus intermedius; W, Whole body program.

REST AND STRENGTH – NEURONAL TRAINING

Prescription

It is commonly recommended that the optimal rest periods for the development of maximal strength through neuronal training methods are between 120 and 300 seconds, while other sources have recommended the optimal inter-set rest period should simply be greater than 180 seconds. However, the scientific evidence for adopting such a practice also appears equivocal. As discussed previously, a number of sources have not referenced any scientific research to justify their rest period recommendations (Bompa and Cornacchia, 1998; Dowson, 1996; Pauletto, 1986). For example, Bompa and Cornacchia (1998) recommended the use of between 180 and 300 seconds inter-set rest periods but do not reference any empirical evidence to justify such claims. As no scientific evidence is referenced, it is difficult to critically evaluate the worth of adopting such practice.

Other authors have cited references which have not actually investigated the effect that different inter-set rest periods have on the development of maximal strength. For example, Baechle and Earle (2000) partially justify their recommendation for 120 seconds rest with a reference to Sewall and Lander's (1991) earlier research. However, Sewall and Lander (1991) investigated the effect of three different inter-session recovery periods (two, six and twenty four hours) on the reliability of repeating a 1RM test for the squat and bench press exercises. Given that this paper did not investigate inter-set rest periods, these findings do not offer any insight into the optimal inter-set rest period. Similarly,

Baechle and Earle (2000) partially base one of their recommendations, for the use of greater than 120 seconds rest, on research by Wagner et al. (1992). The purpose of Wagner et al.'s (1992) research was to investigate whether different grip widths would affect muscular strength during a bench press exercise. Wagner et al. (1992) prescribed a 120 second rest interval between successful 1RM attempts during the 1RM assessments. As there was no manipulation of the inter-set rest period during this study, no insight is offered into the effect of different rest periods during maximal strength development. It would therefore be fallacious to base any recommendations on the findings of such research.

Finally, other authors have referenced articles that have in turn based their recommendations on unsubstantiated assumptions regarding the recovery of metabolites from different resistance training protocols. For example, some authors have based their recommendations on Weiss' (1991) discussion of the dominant energy systems during resistance training, adenosine tri-phosphate and / or phosphocreatine resynthesis rates, and the theorised rest required to maximise the resynthesis of these substrates. As clearly acknowledged by Weiss (1991), there are a number of questions and issues in this area that are currently unclear, including the question of whether an increasing reliance on anaerobic glycolysis during resistance training would impair the ability of the muscle to generate the tension required to maintain the prescribed training intensity. Given these uncertainties, Weiss (1991) suggested that practitioners may be wise to take a conservative approach (e.g. 180-240 seconds) when prescribing the inter-set rest interval. Therefore, despite a number of sources citing Weiss' (1991) suggestion as justification for their inter-set rest period

recommendation, Weiss (1991) does not actually provide, or claim to provide, any conclusive empirical evidence that these rest intervals are optimal for the development of maximal strength.

Research – Inter-set Rest Training

Literature directly investigating the effects of rest on maximal strength development using near maximal loading schemes (neuronal training) is extremely limited. The use of a wide variety of different modes of dynamometry (isometric, isokinetic, isoinertial) and loads not typical of maximal strength training limit our understanding regarding the possible effect of rest on isoinertial training and assessment. For example, previous research conducted by Pincivero et al. (1999) and Parcell et al. (2002) assessed maximal strength using isokinetic dynamometry, while Linnamo et al. (1998) employed isoinertial training and isometric assessments. As isometric and isokinetic dynamometry do not replicate the movement patterns (e.g. the influences of acceleration and deceleration, the coupling of eccentric and concentric contractions, etc.) of athletic performance, the relationship of these findings to isoinertial training and assessment may be questionable (Cronin, McNair and Marshall, 2002; Pearson and Costill, 1988).

Additionally, some studies (Pierce, Rozenek and Stone, 1993; Robinson et al., 1995) have investigated training-induced improvements in maximal strength but have employed lighter loads (e.g. 10RM) than those typically used for the development of maximal strength (1-6RM). As it is thought that loads greater than 80%1RM are required to produce further neural adaptations during

resistance training in experienced lifters (Kraemer et al., 2002), these lighter loads are not consistent with typical loading parameters, and limit the relation of the results to neuronal strength training. To our knowledge there have been no previous studies directly investigating the effect of different inter-set rest intervals on the development of maximal strength with neuronal loading parameters. The literature that has investigated strength development with neuronal loading parameters (see Table 3) has compared the efficacy of these parameters to other loading schemes (e.g. hypertrophy). It would appear from Table 3 that those studies that have used 180 seconds inter-set rest resulted in average increases of 15% in upper body strength and 16% in lower body strength (Brandenburg and Docherty, 2002; Chestnut and Docherty, 1999; Robinson et al., 1995; Young and Bilby, 1993), while studies that used 120 seconds inter-set rest resulted in average increases of 32% in upper body strength and 20% in lower body strength (Calder et al., 1994; Chestnut and Docherty, 1999; Schlumberger, Stec and Schmidtbleicher, 2001). However, given the limitations of the current literature, it is impossible to make any definitive conclusions regarding the possible role of rest in the strength improvements observed.

Despite employing loads typical of hypertrophy schemes (10RM), research undertaken by Robinson et al. (1995) may offer limited insight into the effect of rest on the development of maximal strength through neuronal training methods. Robinson et al. (1995) investigated the effect of three different inter-set rest durations (180, 90 and 30 seconds) on maximal strength development following five weeks of equi-volume training (five sets of 10RM) in 33

moderately trained male subjects. Significantly greater increases in isoinertial 1RM were observed in subjects who rested for 180 seconds (6.8%) compared to subjects who rested for 30 seconds (2.3%), with no significant differences observed in muscle girth for all groups. However, as discussed earlier, Robinson et al. (1995) did not report whether the increases in the group prescribed 90 seconds rest were significantly different from the group who rested for 180 seconds or not, which limits our understanding of the possible effect of rest on strength development. Therefore while the results of this study may suggest that longer rest periods (approximately 180 seconds) are superior for maximal strength development, the reader must be aware of the limitations associated with this study.

Research – Inter-repetition Rest Training

Folland and colleagues (2002) investigated the effect of nine weeks training with an inter-repetition rest protocol on the development of maximal strength. Similar increases in maximal strength (34 – 40%) were observed for a continuous and a 30 second inter-repetition rest protocol in 23 untrained male ($n = 15$) and female ($n = 8$) subjects. Folland et al. (2002) argued that the similarity in strength gains between groups suggested that fatigue is not a necessary stimulus for the development of strength. However, while this study equated the number of sets (four), repetitions (ten) and starting load (75%1RM), the authors developed an extremely fatiguing continuous protocol which resulted in the need to decrease the training load two to three times per training session. These decreases in the training load, reported by Folland et al. (2002), indicate that the rest intervals were not the only difference between the

training groups and so the results of this study should be interpreted with caution.

In contrast, Rooney, Herbert and Balnave (1994) found significantly greater strength increases, in 42 untrained male ($n = 18$) and female ($n = 24$) subjects, with a continuous protocol (56%) as compared to a equi-volume inter-repetition (30 seconds between contractions) rest protocol (40%). These findings led the authors to suggest that fatigue is a necessary stimulus in the development of maximal strength. These results would also seem to suggest that continuous training schemes offer a superior training stimulus for the development of maximal strength than inter-repetition rest training schemes.

Further confounding understanding in this area are the conflicting results reported by Byrd, Centry and Boatwright (1988). Byrd et al. (1988) examined the effects of ten weeks of continuous and inter-repetition training in fifty recreationally trained male subjects. The subjects were randomly assigned to train with a continuous, a one second inter-repetition rest, or a two second inter-repetition rest scheme. While the primary concern of this study was to investigate the effect of inter-repetition rest training on power development, pre- and post-training strength measures were also investigated. A greater increase in bench press strength was observed after training with the one second inter-repetition rest loading scheme (30%) compared with the continuous (25%) and two second inter-repetition rest (23%) loading schemes. In contrast however a significantly greater increase in leg press strength was observed after training with the continuous scheme (58%) compared with the

one second (17%) and two second (14%) inter-repetition rest loading schemes. Therefore it is apparent that debate exists within the literature regarding the efficacy of inter-repetition rest training for the development of maximal strength.

Table 3: Effect of different training protocols and rest durations on maximal strength development

Author(s)	Subjects	Training Duration	Frequency and Protocols	Tempo	Rest (s)	Measures	Results		
							Strength % Change	P ≤	
Brandenburg & Docherty (2002)	18 Male T	9 weeks (2 x weeks 1-2) (3 x weeks 2-9)	4 x 10RM	2 s ↑	180	1RM	Elbow Flex	11	.05*
				2 s ↓			Elbow Ext.	15	.05*
			Extra ECC load (3 x 10RM CON)	2 s ↑	180		Elbow Flex	9	.05*
			(3 x 10 x 110% ECC)	2 s ↓			Elbow Ext.	24	.05**
Calder et al. (1994)	30 Female U	10 weeks Whole = 2 x week Split = 2 x UO + 2 x LO x week	Whole Body Programme	N/A	120	1RM	Elbow Flex	54	.001*
			Upper (5 x 6-10RM)				BPress	33	.001*
			Lower (5 x 10-12RM)				Leg Press	21	.001*
			Split Programme	N/A	120		Elbow Flex	69	.001*
			Upper (5 x 6-10RM)				BPress	32	.001*
			Lower (5 x 10-12RM)				Leg Press	22	.001*
Chestnut & Docherty (1999)	24 Male U	3 x 10 weeks	6 x 4 RM	N/A	180	1RM	Elbow Flex	13.7	.05*
							Elbow Ext.	16.9	.05*
			3 x 10RM	N/A	120		Elbow Flex	10.6	.05*
							Elbow Ext.	18.1	.05*
Pierce et al (1993)	23 Male U	2 x 3 x 8 weeks	Progressive (3 x 10RM x week 1-3) (3 x 5RM x week 4-5) (3 x 10RM x week 6-8)	N/A	150	1RM	Squat	23.2	.05*
Robinson et al. (1995)	33 Male T	4 x 5 weeks	Inter rep (5 x 10RM)	N/A	180	1RM	Squat	7.3	.05**
			Inter rep (5 x 10RM)	N/A	90		Squat	5.8	.05*
			Inter rep (5 x 10RM)	N/A	30		Squat	2.4	.05*
Rooney et al (1994)	18 Male, 24 Female U	3 x 6 weeks	30 s inter-rep rest (1 x 6RM)	N/A	N/A	1RM	Elbow Flex	41.2	.001*
			Continuous (1 x 6RM)	N/A	N/A		Elbow Flex	56.3	.001**
Schlumberger et al. (2001)	27 Female T	2 x 6 weeks	Single-set (6-9RM)	N/A	N/A	1RM	BPress	4.1	—**
							Leg Ext.	6.7	.05*
			Multiple-set (3 x 6-9RM)	N/A	120		BPress	10.4	.05**
						Leg Ext.	15.8	.05**	

Young & Bilby (1993)	18 Male U	3 x 7 ½ weeks	Explosive (4 x 8-12RM)	FAST	180	1RM	Squat	19.9	.01*
			Slow (4 x 8-12RM)	SLOW	180	Squat	22.0	.01*	

NOTE: *, within group contrast; †, between group contrast; BPress, bench press; CON, concentric phase; ECC, eccentric phase; Ext., extensors / extension; Flex, flexors / flexion; LO, lower body only; RM, repetition maximum; s, seconds; T, trained; U, untrained; UO, upper body only.

REST AND POWER TESTING

Inter-repetition Rest Periods – Power Testing

There is a shortage of research directly investigating the effect of inter-repetition rest intervals on power (also known as speed-strength) during isoinertial resistance exercise. While previous research has been conducted with isokinetic dynamometry, the failure of isokinetic dynamometry to accurately describe the movement patterns of isoinertial training and functional performance limit our understanding. However, previous research investigating the effect of different rest periods on vertical jump performance has observed no significant difference in drop jump height with 15, 30 or 60 seconds rest between jumps, suggesting that 15 seconds rest may be sufficient to allow an athlete to successfully repeat a maximal effort drop jump (Read and Cisar, 2001).

Inter-set Rest Periods – Power Testing

When performing multiple repetitions, it has been observed that short rest periods can significantly impair an athlete's ability to produce maximal power. For example, Abdessemed et al. (1999) observed no significant reduction in mean power, during 10 sets of heavy resistance exercise, when 180 or 300 seconds inter-set rest was prescribed. However, significant decreases in power were observed, both between and within sets, when the rest interval was reduced to 60 seconds. Abdessemed et al. (1999) therefore argued that the length of the inter-set rest periods had a significant influence on subsequent

muscle performance, and that 180 seconds rest appears sufficient to maintain constant power outputs during exercise with multiple repetitions. While these findings suggest that short rest periods (e.g. 60 seconds) may be counterproductive in the development of muscular power, it is disappointing that additional rest periods of approximately 90 and 120 seconds were not included, as the data from these additional rest periods may have aided scientific understanding in this area.

REST AND POWER TRAINING

Prescription

Despite the lack of conclusive evidence regarding the effect of rest on the development of muscular power, it is commonly recommended that the optimal rest periods are identical to those prescribed for neuronal strength development (e.g. between 180 and 300 seconds). For example, Baechle and Earle (2000), Kraemer et al. (2002) and Wilson (1999) all suggested that the rest intervals for power development should be the same as neuronal strength training, however, there is no empirical evidence, to our knowledge, to suggest that these two qualities respond optimally to the same rest durations.

As these recommendations for power development are the same as for the development of neuronal maximal strength, the majority of the recommendations are based on the same references previously discussed. Therefore these recommendations are subject to the same criticisms also discussed previously. Once more, a number of authors have published

recommendations for the optimal inter-set rest period without citing any evidence to justify such claims (Dowson, 1996; Kraemer et al., 2002; Schmidtbleicher, 1992), or have based recommendations on misguided interpretations of research (Kraemer and Ratamess, 2004) discussed earlier. Therefore the adoption of such practices would appear unsound given the lack of scientific evidence regarding the effect of different rest intervals on power development during isoinertial training.

Research – Inter-set Rest Training

It is widely acknowledged that the development of muscular power is fundamental to successful performance in many athletic activities (Kraemer et al., 2002; Lawton et al., In Press), however, to our knowledge, no previous training studies have directly investigated the effect of rest on power development. In fact, much of the research in this area has involved inquiry into the optimal training loads, the role of velocity specificity and the efficacy of ballistic weight training techniques, while rest has been largely ignored. Previous training studies that have included rest as a variable of interest (see Table 4) have employed protocols with equal volumes of rest, and the methodological differences between these studies render the findings incomparable. It appears from Table 4 that those studies that have used 180 seconds inter-set rest resulted in average increases of 2.0% in upper body power and 10% in lower body power (McEvoy and Newton, 1998; Wilson, Newton, Murphy and Humphries, 1993; Young and Bilby, 1993), while studies that used 120 seconds inter-set rest resulted in an average increase of 14% in the lower body (Jones, Bishop, Hunter and Fleisig, 2001; Kraemer et al., 2003). It is

important to remember, however, that differences in the training duration, subject demographics, training loads, and the methods and / or tools used to assess muscular power have confounded our understanding in this area. For example, Kraemer et al. (2003) examined the efficacy of nine months of periodised and non-periodised training programmes on power development in 30 untrained female subjects using countermovement jump height as their performance measure whereas McEvoy and Newton (1998) investigated the effect of 10 weeks ballistic weight training (bench throw and squat jump) on the throwing and running speed of 18 trained male baseball players. While Kraemer et al. (2003) employed rest periods of between 90 and 120 seconds, McEvoy and Newton (1998) used longer rest periods (180 seconds). However, given the differences within the other variables (e.g. training duration, subjects, performance measures, etc.) it is impossible to infer as to the effect the different rest periods may have had, if any.

Research – Inter-repetition Rest Training

Research into inter-repetition rest training protocols by Byrd, Centry and Boatwright (1988) examined the effect of two different inter-repetition rest protocols on power output during the PWC₁₇₀ arm cranking exercise. The PWC₁₇₀ is a submaximal test designed to estimate the power output that would elicit a steady state heart rate of 170 beats per minute (Rowland, Rambusch, Staab, Unnithan and Siconolfi, 1993; Wood, 2004). Fifty recreationally trained male subjects were randomly assigned to train for ten weeks with either a continuous, a one second inter-repetition rest, or a two second inter-repetition rest scheme. The authors reported significantly greater power output for the

groups that had been involved with inter-repetition rest protocols than the group that performed their training continuously. While the authors acknowledge that the mechanisms for these increases are yet to be definitively explained, it has been hypothesised that the rests between repetitions increased blood flow reducing lactate accumulation and thereby permitting more work to be done (Byrd et al., 1988).

Table 4: Effect of different training protocols and rest durations on maximal power development

Author(s)	Subjects	Training Frequency and Duration	Protocols	Tempo	Rest (s)	Measures	Strength			Results		
							% Change	P ≤		% Change	P ≤	
Jones et al. (2001)	26 Male T	2 x 10 weeks	Periodised (3 x 15RM, 3 x 8RM, 3 x 5RM)	EXPL.	120	VJ	Squat	16.3	.046 ^{**†}	VJ	3.0	.873 ^{**†}
			Periodised (3 x 10RM, 3 x 5RM, 3 x 3RM)	EXPL.	120	Jump Squat (30%1RM) (50%1RM) 1RM	Squat	11.5	.046 [*]	30%1RM 50%1RM VJ 30%1RM 50%1RM	5.9 11.8 -1.2 5.0 2.9	.032 [*] .046 [*] .873 ^{**†} .032 [*] .046 [*]
Kraemer et al. (2003)	30 Female U	3 x week x 9 months	Periodised (4-6RM, 8-10RM, 12-15RM)	N/A	90-120	CMJ 1RM	Leg Press BPress	19 23	.05 ^{**†} .05 ^{**†}	CMJ	~50	.05 ^{**†}
			8-10RM	N/A	90-120		Leg Press BPress	17 17	.05 [*] .05 [*]	CMJ	~37	.05 [*]
McEvoy & Newton (1998)	18 Male T	3 x biweekly x 10 weeks	3 x 6-8MVC (Bench throw + squat jump)	EXPL.	180	Throw speed (18.44 m)	N/A	N/A	N/A	Throw	2.0	.05 [*]
						Sprint (27.4 m)	N/A	N/A	N/A	Sprint	9.0	.05 [*]
Wilson et al. (1993)	55 Male T	2 x 10 weeks	Progressive (3-6 x 6-10RM)	N/A	180	SJ	Leg Ext.	8.7	- ^{**†}	CMJ	4.8	.05 [*]
			Plyometric (3-6 x 6-10 depth jumps x 0.2-0.8m)	EXPL.	180	CMJ	MVIF	14.4	.05 [*]	SJ	6.3	.05 [*]
						Isokinetic leg ext. MVIF	Leg Ext.	1.3	- ^{**†}	CMJ	10.3	.05 [*]
			Max power (3-6 x 6-10 jump squats @ 30%MVIF)	EXPL.	180		MVIF	0.7	- ^{**†}	SJ	6.5	- ^{**†}
						Leg Ext.	7.0	.05 [*]	CMJ	16.8	.05 ^{**†}	
							MVIF	2.0	- ^{**†}	SJ	14.8	.05 ^{**†}
Young & Bilby (1993)	18 Male U	3 x 7 ½ weeks	Explosive (4 x 8-12RM)	EXPL.	180	1RM	Squat	21.0	.01 [*]	VJ	4.7	.01 [*]
			Slow (4 x 8-12RM)	SLOW	180	VJ	Squat	22.5	.01 [*]	VJ	9.3	.01 [*]

NOTE: *, within group contrast; †, between group contrast; BPress, bench press; CMJ, countermovement jump; ext., extension; EXPL., explosive; MVIF, maximum voluntary isometric force; N/A, not applicable / not available; RM, repetition maximum; s, seconds; SJ, static jumps; T, trained; U, untrained; VJ, vertical jump.

INTRA-SET REST TRAINING

Although traditionally resistance training has employed continuous training schemes with inter-set rest periods, intra-set rest training methods which distribute rest intervals between groups of repetitions have also been investigated (Lawton et al., 2004). It has been theorised that the short rest periods within the training set allow partial resynthesis of intramuscular phosphocreatine stores (Berg, 2003), potentially allowing an athlete to increase their training volume by training at high intensities for longer durations, or performing additional repetitions (Berg, 2003). This is thought to lead to an increased exposure of the muscle to the kinematic and kinetic (e.g. increased time under tension, high force development, the performance of additional work, etc.) stimuli thought important for the development of maximal strength, power and hypertrophy whilst minimising the performance-inhibiting effects of metabolic accumulation and substrate depletion. Therefore, theoretically, intra-set rest training could potentially provide a greater stimulus for the development of strength and hypertrophy than continuous training methods. However, the literature in this area is still in its infancy, and many of the theories surrounding intra-set rest training are currently unsubstantiated. To our knowledge only two papers have investigated the effect of intra-set rest training schemes (Lawton et al., 2004; Lawton et al., In Press).

Lawton et al. (In Press) investigated the differences between an inter-repetition rest scheme (20 seconds inter-repetition rest), an intra-set rest scheme whereby subjects rested after two repetitions (50 seconds rest), and an intra-set rest scheme whereby subjects rested after three repetitions (100 seconds rest) in 26

elite junior male basketball and soccer players. The training schemes were equated by the number of repetitions (six repetitions), load (6RM) and time to complete the set (118 seconds). As power output was the performance measure of interest, subjects were instructed to perform each concentric contraction explosively. It was observed that the two intra-set rest schemes resulted in significantly higher power outputs during the later part of the set compared to continuous schemes, while the power output between the two intra-set rest schemes were similar. However, as this study only measured power output the inferences we can draw from these results are limited. Additionally, while the authors suggested that intra-set rest training may result in superior strength and power adaptation compared to continuous training, they also acknowledged the limitations of this research and suggested that further research was needed to investigate the mechanical, hormonal, neural and metabolic profiles of intra-set rest training schemes (Lawton et al., In Press).

Lawton et al. (2004) investigated the effects of six weeks of training with continuous (four sets of six repetitions performed every 260 seconds) and an intra-set rest training (eight sets of three repetitions performed every 113 seconds) scheme equated by volume and total time in 26 elite junior male basketball and soccer players. Before training each subject was assessed for strength (6RM assessment) and muscular power. Power was ascertained by the mean power of two trials of bench press throws at loads of 20, 30 and 40 kg. After initial testing subjects were matched by sport, test results and training experience and randomly assigned to either the continuous or intra-set rest training schemes (Lawton et al., 2004). As power was the performance measure

of interest subjects were instructed to perform the concentric phase of each repetition as explosively as possible. After the six week training intervention, subjects were reassessed for muscular strength and power. The authors reported significantly greater increases in strength with the continuous scheme (9.7%) compared to the intra-set rest training scheme (4.9%), while they reported that neither form of training was superior for improving power output. They also suggested that intra-set rest training may provide a method of reducing overload fatigue and attaining higher power output per repetition while maintaining prescribed training volumes (Lawton et al., 2004). It was recommended that further research be conducted into the effects of intra-set rest training, especially profiling the metabolic and hormonal responses.

SUMMARY

Given the importance of strength and power in everyday activities and athletic performance, the lack of scientific understanding regarding the effect of different rest periods on the development of these qualities is astounding. It has been widely acknowledged that rest is an important variable to consider during the development of resistance training programmes however much of the literature has instead focussed on the efficacy of different loading schemes (e.g. load used, number of sets and / or repetitions used, etc.) and techniques (e.g. ballistic weight-lifting, traditional weight-lifting, plyometrics, etc.) while largely ignoring the effect of rest. While some research has been conducted in this area, the methodological inconsistencies between, and within, studies have rendered the results incomparable and inferences about the effect of different rest periods problematic.

Research into the effect of inter-repetition rest intervals has mainly focused on acute studies of force recovery after different rest intervals with the aim of establishing a common rest period for maximal strength and power testing. Therefore, the research in this area has examined the duration of rest required to allow an athlete to successfully repeat a 1RM lift or vertical jump. Studies into maximal strength testing have suggested that relatively short rest periods (e.g. 60 seconds) appear sufficient to allow an athlete to successfully repeat a maximal contraction, while studies investigating power testing have suggested that even shorter rest periods (e.g. 15 seconds) appear sufficient to repeat maximal height drop jumps. However, it has been demonstrated that when multiple repetitions are performed longer rest periods may be necessary to maintain the desired training intensity. Unfortunately research directly investigating the optimal length of inter-set rest periods, during multiple repetitions, is limited by the methodological inconsistencies discussed earlier. Therefore to our knowledge, there is no conclusive empirical evidence regarding the optimal inter-set rest interval for the development of maximal strength and power.

The recommendations, on which many health and sport professionals have based their practice, appear to be based on anecdotal evidence, are completely unsupported by any scientific enquiry, or are based on inconclusive research or misguided interpretations. Given the lack of empirical evidence regarding the optimal inter-set rest period for the development of maximal strength and

power it would appear questionable to adopt the rest intervals recommended by many of these sources.

In addition to the question of identifying the optimal inter-set rest period for maximal strength and power development using continuous loading schemes, the influence of “chunking” these rest periods differently also needs to be investigated. Intra-set rest schemes provide an additional method for the prescription of rest during resistance exercise however the efficacy of adopting such a practice is relatively unknown. The limited research to date concerning intra-set rest training has suggested that these schemes may provide superior stimuli for neuronal strength and power development as it is thought that intra-set rest training may increase the exposure of the muscle to the mechanical stimuli (e.g. high forces) thought necessary for the development of strength and power, whilst minimising the performance inhibiting effects of metabolic accumulation and substrate depletion. While previous research has observed greater power output with intra-set rest training compared to continuous training schemes, the kinematic, kinetic and blood lactate profiles of intra-set rest training are not known. Therefore, an assessment of the acute responses of these variables to intra-set rest training may offer some greater understanding regarding the efficacy of these methods. Answers to such questions should improve the efficacy of strength training prescription.

CHAPTER THREE: THE KINEMATIC, KINETIC AND BLOOD LACTATE PROFILES OF CONTINUOUS AND INTRA-SET REST LOADING SCHEMES

PRELUDE

It would seem from the literature that there is a general lack of understanding regarding the influence of rest on the development of strength and power. Furthermore, the optimal durations of rest for maximising strength and power adaptation are not known. However, despite this, a number of authors have published recommendations for the optimal inter-set rest periods which have been disseminated to coaches, students and other health professionals with no conclusive empirical evidence to support the adoption of such practice.

While continuous loading schemes with inter-set rest periods have traditionally been prescribed for resistance exercise, loading schemes with intra-set rest periods have also been investigated. Intra-set rest loading methods involve chunking the volume of work into smaller work units and prescribing rest periods between these chunks. The development of these intra-set rest schemes has raised a number of questions regarding the effects of such training on the development of strength and power. It is thought that a greater understanding regarding rest and its influence on strength and power adaptation may be gained through investigating the mechanical and metabolic profiles of continuous and intra-set rest loading. Therefore, the purpose of this study was to examine the acute kinematic, kinetic and blood lactate responses to continuous and intra-set rest loading schemes.

INTRODUCTION

Muscular strength and power have been identified as important determinants of everyday activity and athletic success (Komi and Hakkinen, 1988) and are most commonly trained through isoinertial (constant gravitational load) resistance training. Given the nature of resistance training, which involves the repeated activation and contraction of skeletal muscles, there is no doubt that continuous training will ultimately result in failure to sustain the desired and / or required training intensity (Nigg et al., 2000) especially when performing multiple sets and / or repetitions. Therefore, rest periods and their duration become an important consideration when prescribing resistance exercise.

Typically, strength training which aims to improve strength through increasing the cross-sectional area of the muscle (hypertrophy) has used relatively short rest periods (60-90 seconds), whereas neuronal strength and power training are typified by longer rest periods (180-300 seconds). However, the scientific rationale upon which these rest periods are based remains relatively unsupported in the literature. That is, very little research has investigated the effect of different rest intervals on the development of maximal strength and power. Further confounding understanding in this area is that in most circumstances researchers and authors have quoted each other without citing original research (Baechle and Earle, 2000) or have misinterpreted findings in this area (Kraemer et al., 2002; Kraemer and Ratamess, 2004). In fact, it is difficult to find empirical evidence justifying the adoption of the

recommendations disseminated to students, athletes, coaches and health professionals through textbooks, coaching manuals and review articles.

While continuous loading schemes with inter-set rest periods have been traditionally prescribed during resistance exercise, intra-set rest loading schemes have also been investigated (Lawton et al., 2004). Intra-set rest training refers to training that “chunks” a set or sets into a smaller work unit or units with more intermittent rest periods (e.g. three sets of 6RM and 180 second rest periods vs. six sets of three repetitions of 6RM load and 72 second rest periods). It has been theorised that the short rest periods within the training set allow the partial resynthesis of the intramuscular phosphocreatine stores (Berg, 2003), allowing greater force and power output in the later stages of the workout (Lawton et al., 2004; Lawton et al., In Press). Intra-set rest loading is also thought to allow the athlete to increase their training volume by training at high intensities for longer durations and / or performing additional repetitions.

The resultant kinematics and kinetics associated with training (e.g. greater force and power output, greater time under tension, greater total work, etc.) are thought important for the development of maximal strength and power whilst simultaneously minimising the performance-inhibiting effects of metabolic accumulation and substrate depletion (Byrd et al., 1988; Lawton et al., 2004; Lawton et al., In Press). However, research in this area is still in its infancy and so many of the theories regarding intra-set rest loading schemes are currently unsubstantiated. Therefore the purpose of this study was to compare the acute kinematic, kinetic and blood lactate responses to continuous and two different

intra-set rest loading schemes. It is thought that such an investigation will improve our understanding of intra-set rest loading and subsequent application as a resistance strength training method.

METHODS

Experimental Design

A cross-over experimental design was used to investigate the acute responses to the three different loading schemes. The loading schemes were assigned to the participants through a block randomisation design, to negate any possible order effects.

Subjects

Sample size calculations, based on data obtained during pilot testing (data not presented), indicated that ten subjects would be required to detect a moderate effect with a statistical power of 80% at an alpha level of $P < 0.05$. Ten healthy male subjects volunteered to participate in this study, which was evaluated and approved by the Human Subject Ethics Committee of the Auckland University of Technology. Subjects were required to have a minimum of twelve months resistance training experience and were pre-screened for any previous or current injuries and medical conditions that would contraindicate participation. Additionally, subjects signed an informed consent document before testing commenced. During data collection one subject withdrew from the study for unknown reasons leaving nine subjects. The data from this subject was not

included in any analyses. The descriptive characteristics of the subjects that completed the study are presented in Table 5.

Table 5: Participant descriptive characteristics

Age (years) mean (SD)	Height (cm) mean (SD)	Body Mass (kg) mean (SD)	Bench Press (6RM) mean (SD)
25.2 (4.5)	178.5 (4.7)	79.7 (10.8)	80.8 (26.5)

Equipment

A counter-weighted isoinertial Smith machine (Fitness Works, Auckland, New Zealand) capable of weight increments of 1.25kg was used for all strength assessments and testing sessions. The Smith machine was chosen for safety, easy instrumentation, availability and subject familiarity. A mechanical brake was employed at all times to allow standardisation of joint angles (range of motion) and to ensure subject safety. This brake was positioned at the lowest point of the eccentric phase and did not influence the movement patterns during testing in any way.

Figure 1: Modified Smith machine



Attached to the bar of the Smith machine was a linear position transducer (PA80, Unimeasure, Oregon – mean sensitivity 0.499mV/V/mm, linearity 0.05% full scale) which measured vertical displacement with an accuracy of 0.01cm. Displacement data was sampled at 1000Hz and collected by a laptop computer (Toshiba, Japan) running custom built data acquisition and analysis software (LabView 6.1, National Instruments, Austin, Texas).

Blood samples were analysed through portable blood glucose (Accu-Chek, Roche, Auckland, New Zealand) and blood lactate (Lactate Pro, Arkray, Japan) analysers. Blood glucose and lactate accumulations were measured and recorded to the nearest 0.1mmol/L.

A portable stadiometer and digital scales (Model 770, Seca, Germany) were used to measure height (cm) and body weight (kg) respectively. Height was measured and recorded to the nearest 1cm, while body weight was measured and recorded to the nearest 0.1kg.

An electronic timer was used to ensure that the correct rest periods were employed for each loading scheme. The electronic timer gave an audio signal when the rest time was completed, cueing the subject to begin the next training set. The investigator also gave subjects a fifteen second count down to ensure that the subjects were properly prepared to begin at the audio cue.

Experimental Testing

During preliminary testing, subjects were tested for height, weight and six-repetition maximum (6RM) bench press strength. The subjects then performed one testing session for each of the loading schemes. Kinematic, kinetic and blood lactate data was collected during each of these sessions. All subjects were familiarised with the bench press exercise, loading schemes, procedures and resistance training equipment prior to testing to eliminate any acute learning effects. A minimum of 48 hours recovery was prescribed between sessions and all sessions were performed at the same time of day to reduce the impact of any diurnal variations.

6RM Assessment

6RM strength for the Smith machine bench press exercise was assessed in accordance with the following protocol. Two warm up sets of seven repetitions at 50% and 70% of the individual's body weight were performed separated by five minutes rest. Grip width was standardised with the hands placed on the bar shoulder width apart. A mechanical brake, discussed previously, was also used to standardise the depth of each eccentric movement and to ensure subject safety. The load was conservatively increased until the subject was able to successfully perform six but not seven repetitions. Five minutes rest was prescribed between each attempt. Subjects were instructed to perform each repetition in a controlled manner and were not allowed to pause at any time. All strength assessments were conducted by the same investigator who judged successful attempts, including full range of motion, for each individual.

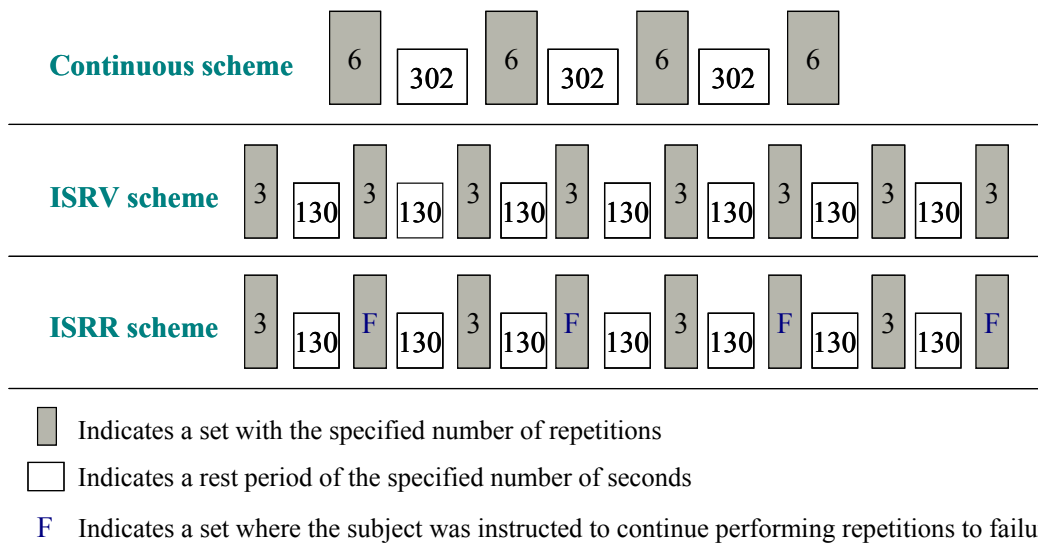
Loading Schemes

Prior to each testing session, a standardised warm up including two warm-up sets with 40% and 75% of the individual's previously established 6RM were performed. Five minutes rest was prescribed between each warm-up set and between the warm-up and the first training set.

Each subject completed three sessions separated by a minimum of 48 hours. To avoid order effects, the scheme to be performed was assigned to each subject in a block randomised design. Each scheme was performed with the previously established 6RM load and subjects were instructed to perform the concentric phase of each repetition as explosively as possible.

The three loading schemes included a continuous loading scheme consisting of four sets of six repetitions separated by 302 seconds rest (CONT), an intra-set rest loading scheme equated by total rest time, volume and load (ISRVT) consisting of eight sets of three repetitions separated by 130 seconds rest, and an intra-set rest loading scheme equated by total rest time and load (ISRR). This final scheme consisted of eight sets of exercise however, while sets one, three, five and seven consisted of three repetitions, subjects were instructed to perform sets two, four, six and eight to voluntary failure. Once more, 130 seconds rest was prescribed between training sets. A graphical representation of the three schemes can be observed in Figure 2.

Figure 2: Graphical representation of the continuous and intra-set rest loading schemes.



Blood Sampling

On experimental days, blood samples were obtained from a finger of the non-dominant hand using sterile techniques. Blood lactate samples (approximately 3 μ l) were obtained after ten minutes seated rest (Pre), immediately post-exercise (P0), five minutes (P5), fifteen minutes (P15), and thirty minutes (P30) post-exercise. Blood glucose samples (approximately 3 μ l) were obtained pre-exercise only (Pre).

Data Analysis

The raw displacement time data was filtered using a low pass Butterworth filter with a cut-off frequency of 5 Hz, in accordance with previous research that has used double-differentiation to derive the kinetic variables of interest (Crewther, 2004; Cronin and Owen, 2004; Cronin, McNair and Marshall, 2000). This

filtered displacement time data was then differentiated to determine the other kinematic variables (velocity and acceleration). The kinetic variables (force, impulse, work and power) were then derived through the differentiation of these kinematic variables (see Appendix 8 for the mathematical formulae used). Data was calculated for the eccentric (defined as the period from maximum to minimum vertical displacement) and concentric (defined as the period from minimum to maximum vertical displacement) phases of each repetition.

Statistical Analysis

Eccentric and concentric time under tension, force, power and work done was calculated for each repetition and summed to give the total for each set of each loading scheme (CONT, ISRV and ISRR). These set totals were then summed to provide eccentric, concentric and overall totals for the entire session, which were then analysed. Impulse was calculated as the area under the force time graph. Total time under tension, force, power, impulse and work done during each loading scheme were compared for significant differences using a one-way repeated measures analysis of variance (ANOVA) and Holm-Sidak post-hoc contrasts. Lactate responses were compared using a two factor [groups (three) and time (five)] repeated measures ANOVA. Where a statistical difference or interaction was apparent, a post-hoc Bonferroni adjusted pair-wise comparison was used to determine the nature of the difference. Statistical analyses were performed using SPSS 11.5 (SPSS Inc., Chicago, Illinois) and the criterion level for statistical significance was set at an alpha level of $P < 0.05$.

RESULTS

The reliability (co-efficient of variation = 1.5%, intraclass correlation coefficient = 0.98) associated with the 6RM strength assessment established during pilot testing was high indicating the baseline maximal strength measure used in this study was stable across testing occasions. However, as can be observed in Table 6, when subjects used the ISSR loading scheme a significantly greater number of repetitions (~30) were able to be performed compared to the other two loading schemes (~24). The greatest number of extra repetitions was performed earliest in the workout (Set two = 7.0 repetitions) after which there was a steady decline.

Table 6: Number of repetitions completed per set during the continuous and intra-set rest loading schemes.

	CONT Mean (SD)	ISRV Mean (SD)	ISRR Mean (SD)
Set 1	6.0 (0.0)	3.0 (0.0) 3.0 (0.0)	3.0 (0.0) 7.0 (1.1)
Set 2	6.0 (0.0)	3.0 (0.0) 3.0 (0.0)	3.0 (0.0) 6.0 (1.5)
Set 3	6.0 (0.0)	3.0 (0.0) 3.0 (0.0)	3.0 (0.0) 5.8 (1.6)
Set 4	5.6 (1.1)	3.0 (0.0) 3.0 (0.0)	3.0 (0.0) 4.4 (1.5)
	TOTAL		
Total	23.6 (1.1)	24.0 (0.0)	30.8 (7.5)

The mean (\pm standard deviation) for the summed kinematic and kinetic variables of interest are presented in Table 7. It can be observed from Table 7 that the ISRR scheme resulted in significantly greater summed eccentric, concentric and total values for all the variables studied, while no significant

differences were observed between the CONT and ISRV schemes for any of the summed kinematic and kinetic variables examined. Summed total time under tension (~53% overall), total mean force (~62% overall), total impulse (~59% overall), total mean power (~63% overall) and total work done (~65% overall) were significantly greater than the CONT and ISRV schemes. The greater summed kinematic and kinetic values associated with ISRR loading was to be expected as this scheme enabled extra repetitions (see Table 6) to be performed than the CONT and ISRV schemes.

Table 7: Kinematic and kinetic responses to the continuous and intra-set rest loading schemes

Variables	CONT Mean (SD)	ISRV Mean (SD)	ISRR Mean (SD)	P value
<i>Eccentric Phase</i>				
Summed Duration (s)	20.4 (3.3)	18.4 (3.2)	29.9 (6.9) ^{# †}	0.006
Summed Mean Force (N)	19028 (6756)	19122 (6847)	30769 (8511) ^{# †}	0.006
Summed Impulse (N.s)	14935 (4135)	13460 (3281)	21207 (3698) ^{# †}	0.002
Summed Mean Power (W)	6553 (2210)	6701 (2259)	11484 (4474) ^{# †}	0.007
Summed Work (J)	9288 (1356)	9732 (1331)	14577 (1834) ^{# †}	<0.001
<i>Concentric Phase</i>				
Summed Duration (s)	33.0 (14.7)	30.1 (9.6)	58.9 (14.2) ^{# †}	<0.001
Summed Mean Force (N)	19051 (6746)	19165 (6839)	30780 (8520) ^{# †}	0.006
Summed Impulse (N.s)	27198 (14067)	25560 (13253)	47172 (16113) ^{# †}	<0.001
Summed Mean Power (W)	4609 (1647)	4774 (1140)	6555 (1522) ^{# †}	0.025
Summed Work (J)	9417 (1718)	9769 (1274)	14957 (2037) ^{# †}	<0.001
<i>Total</i>				
Summed Duration (s)	49.2 (11.3)	45.2 (8.2)	87.8 (16.2) ^{# †}	<0.001
Summed Mean Force (N)	38079 (13502)	38257 (13685)	61549 (17031) ^{# †}	0.006
Summed Impulse (N.s)	42423 (20241)	37399 (14763)	68103 (20424) ^{# †}	<0.001
Summed Mean Power (W)	11161 (3663)	11475 (2907)	18039 (5872) ^{# †}	0.007
Summed Work (J)	18705 (3035)	19502 (2757)	29515 (3823) ^{# †}	<0.001

Significantly greater than corresponding CONT value ($P < 0.05$)

† Significantly greater than corresponding ISRV value ($P < 0.05$)

NOTE: The P values reported are for the initial one-way repeated measures analysis of variance (ANOVA), not the Holm-Sidak post-hoc contrasts.

In terms of the two schemes equated by volume, no significant differences were observed between summed eccentric ($P = 0.166$), concentric ($P = 0.655$) or total ($P = 0.974$) time under tension, despite shorter summed total contraction durations (~4 seconds) being associated with the ISRV loading scheme. Similarly, no significant differences were observed between summed eccentric ($P = 0.164$), concentric ($P = 0.814$), or total ($P = 0.362$) impulse, despite lower values (~2000 Newton-seconds) being associated with the ISRV loading scheme. It is important to note, however, that the relatively small sample size employed within this study, and the subsequent negative effect on the ability to detect small effects, may explain the lack of significant differences observed between the CONT and ISRV loading schemes. Also, despite being asked to perform the concentric phase as explosively as possible, the eccentric phase was quicker (~39%) than the concentric phase during all loading schemes.

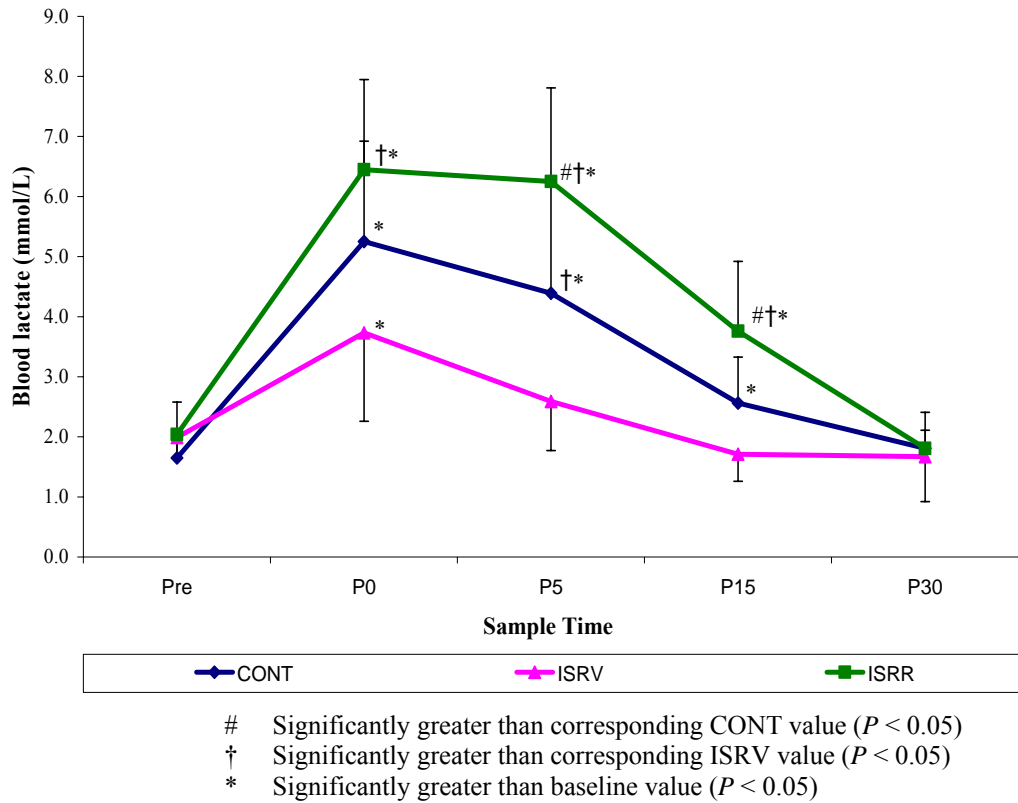
From further analysis it appears that the ISRR loading scheme had a greater influence on the summed concentric time under tension (~66%) and impulse (~69%) compared to the summed eccentric time under tension (~34%) and impulse (~31%). Subsequently, ISRR loading had a greater influence on the summed eccentric mean power (~64%) than the summed concentric mean power (~36%). In terms of summed mean force and work, the ISRR loading scheme had a similar influence on the concentric and eccentric phases.

Pre-exercise blood lactate and blood glucose concentrations (blood glucose data not presented) were not significantly different between sessions (see Figure 3).

In terms of blood lactate response over time, the CONT and ISRR schemes resulted in significant increases in blood lactate concentrations, compared to pre-exercise, from immediately post-exercise (P0) to fifteen minutes post-exercise (P15), whereas the ISRV scheme resulted in significantly elevated blood lactate concentrations immediately post-exercise (P0) only. All schemes had returned to pre-exercise blood lactate concentrations by thirty minutes post-exercise (P30).

With regards to between group blood lactate responses, immediately post-exercise (P0) the blood lactate responses to the ISRV and CONT loading schemes were not significantly different from each other, but the ISRR scheme was significantly greater (34%) than the ISRV scheme. Five minutes post-exercise (P5), the ISRR scheme was observed to have a significantly greater blood lactate concentration than the ISRV (103%) and CONT (36%) schemes, while the CONT scheme was significantly greater (50%) than that of the ISRV scheme. Fifteen minutes post-exercise (P15), the ISRR scheme was significantly greater than the CONT (30%) and ISRV (74%) schemes, while no significant differences were observed between the CONT and ISRV schemes. No significant differences were observed between loading schemes at thirty minutes post-exercise (P30).

Figure 3: Blood lactate responses to the continuous and intra-set rest loading schemes.



DISCUSSION

Previous comparisons of ISRV and CONT loading schemes observed significantly greater repetition power output during ISRV loading (Lawton et al., 2004). However, despite employing similar loading parameters (6RM), training techniques and repetition grouping, such results were not found in the current study. Instead, no significant differences were observed between the CONT and ISRV schemes in any of the kinematic or kinetic variables investigated. Although not statistically significant, with the exception of P5, lower post-exercise blood lactate (P0 – P15) was associated with the ISRV loading scheme when compared with the CONT loading scheme. Therefore

while Lawton et al. (2004) suggested that ISRV loading may provide a superior stimulus for the development of muscular power, the findings of the current study did not support such a contention but rather we found that the ISRV loading scheme may simply offer an alternative to CONT loading schemes with lower levels of blood lactate accumulation.

Lawton et al. (2004) reported significantly greater concentric time under tension during CONT loading, compared to ISRV loading. Once more, despite employing similar loading parameters, training techniques and repetition grouping, these findings were dissimilar to the findings of the current study. That is, no significant differences ($P > 0.05$) were observed between the CONT and ISRV loading schemes in the current study. However, although not statistically significant, the total time under tension associated with the ISRV loading scheme was shorter (~4 seconds) than the CONT loading scheme. If time under tension is important in the development of maximal strength and hypertrophy, as previously suggested by Bloomer et al. (2000) and Komi (1988), this may explain the findings of Lawton et al.'s (2004) training study where greater strength gains were found with the CONT loading scheme. It is important to note however that the between subject variability within the current study (see standard deviations of Table 7) was greater than that reported by Lawton et al. (2004) for concentric time under tension. Further research, with greater subject numbers than the current study, therefore may be required to further scientific understanding regarding the effect of CONT and ISRV loading on eccentric, concentric and total time under tension.

It was observed that manipulating the rest period, by decreasing the length of each rest period but increasing the frequency of rest prescribed, did not significantly influence the total kinematic or kinetic responses associated with the CONT and ISRV schemes. It would seem that when the total rest prescribed within a training session is equated, CONT and ISRV schemes may offer a similar mechanical stimulus for the development of strength and power. However, it is important to note that these results do not offer any insight into the effects of decreasing the length of inter-set rest periods.

It has been proposed that intra-set loading may allow the athlete to increase their training volume by training at high intensities for longer durations and / or performing additional repetitions (Berg, 2003). To investigate such a contention a loading scheme that allowed extra repetitions to be performed whilst equating the rest durations (ISRR) was included. Indeed, it was observed that “chunking” repetitions and increasing the frequency of the rest periods allowed athletes to perform a greater number of repetitions during the session compared with the CONT loading scheme. These additional repetitions resulted in significantly greater total time under tension, mean force, impulse, mean power, work and post-exercise blood lactate values compared with the other two loading schemes.

Explaining the extra repetitions and subsequent superior kinematics and kinetics is difficult. It may be argued that each subject’s true 6RM was not established. However, the reliability associated with the 6RM strength assessment was high

(coefficient of variation = 1.5%, intraclass correlation coefficient = 0.98) indicating that the 6RM baseline training load used throughout the testing sessions was stable across testing occasions. This reliability was also similar to values previously reported for maximal strength assessments (Abernethy, Wilson and Logan, 1995). Given the reliability of the strength assessment, the training experience of the participants and the block randomised experimental design we consider it unlikely that any of the differences observed between the loading schemes were the result of acute learning effects or strength increases.

It may be speculated that some sort of enhancement occurred similar to that described in the literature that has investigated post-activation potentiation. Post-activation potentiation is the transient increase in muscle contractile performance after previous contractile activity (Sale, 2002). That is, conditioning activities such as maximal voluntary contractions are thought to enhance the force and / or power output of ensuing contractions (Gullich and Schmidtbleicher, 1996). The near maximal voluntary contractions used in this study may have resulted in some form of potentiation that resulted in the extra repetitions, especially early in the loading scheme (e.g. set 2).

More likely however, is that the increased frequency of the rest periods allowed partial resynthesis of intramuscular phosphocreatine stores, the dominant energy source for heavy resistance training of approximately five repetitions (Weiss, 1991). It has been previously observed that within two minutes of rest 50% of the depleted intramuscular phosphocreatine stores can be replenished

(Bogdanis, Nevill, Lakomy and Boobis, 1998). As the rest periods prescribed between sets of ISRR loading were 130 seconds in duration, it would appear possible that similar repletion rates may have occurred in the current study. It could therefore be speculated that the increased frequency of the rest periods may have allowed partial resynthesis of the intramuscular phosphocreatine stores enabling the extra repetitions to be performed. However, the experimental design of this study does not enable further analysis of these possibilities and so the exact cause or causes of the observed enhancement can not be conclusively identified.

Finally, greater post-exercise blood lactate accumulation was associated with the ISRR scheme than the CONT and ISRV schemes. There are a number of mechanisms that may be responsible for such a result. Most likely the greater number of repetitions performed during the ISRR loading scheme and hence greater total work, resulted in greater lactate accumulation. It may also be speculated that as a result of the greater repetition number and associated time under tension that greater vasoconstriction and localised muscle hypoxia occurred, in turn resulting in a greater energy contribution from anaerobic glycolysis. Alternatively, it may be that an accumulative blood lactate effect occurred during the ISRR loading scheme as a result of the short rest periods not allowing sufficient clearance of blood lactate. However, again, the experimental design of this study does not allow further investigation of these possibilities and so the exact cause or causes of the observed increase in lactate accumulation can not be conclusively identified.

PRACTICAL APPLICATIONS

In conclusion, it would seem that intra-set rest loading schemes can provide an additional method for manipulating the training variables (e.g. rest, load, volume, etc.) to alter the kinematics and kinetics and resultant hormonal and metabolic responses associated with resistance strength training. If the loading schemes associated with an acute study of this kind are repeated over a number of occasions, certain strength training responses could be expected given that strength and power adaptation is thought to be influenced by the mechanical, hormonal and metabolic stimuli associated with various loading parameters (Enoka, 2002). Of particular interest are the findings associated with the ISRR loading scheme. The authors take the liberty to briefly speculate upon some of the training implications of their findings.

It has been previously suggested that high time under tension (Bloomer and Ives, 2000; Komi and Hakkinen, 1988), mechanical forces, impulses (Crewther, 2004) and metabolic accumulation (Carey Smith and Rutherford, 1995; Takarada, Sato and Ishii, 2002) may be important in the development of muscular strength and hypertrophy. Given the significantly greater eccentric, concentric and total contraction durations, mean forces, impulses, work and blood lactate responses associated with the ISRR loading scheme, it may be speculated that ISRR loading parameters may offer a superior training stimulus than CONT or ISRV loading parameters for the development of maximal strength and hypertrophy.

In terms of power development, it is thought that training that optimises the contribution of force and velocity will optimise power development. Although significantly greater total mean power (eccentric, concentric and overall) was associated with the ISRR loading scheme, from further analysis it appears that the power outputs associated with this scheme were largely based on the higher mechanical forces associated with ISRR loading. Instead, longer movement durations, therefore slower movement velocities, were associated with ISRR loading. Therefore it may be speculated that if the development of high power output, irrespective of movement velocity, is the critical stimulus for the development of muscular power, then the repeated application of ISRR loading schemes may provide a superior training stimulus to CONT and ISRV loading schemes for the development of muscular power. Alternatively, if movement velocity is important in the development of muscular power then the ISRR loading scheme may not provide an appropriate training stimulus for the development of muscular power. With regards to the CONT and ISRV schemes, similar mean powers were observed between the CONT and ISRV schemes, while greater blood lactate was associated with CONT loading. Therefore it may be speculated that ISRV loading may offer a superior training stimulus for the development of muscular power if power training needs to be performed with minimal influence from fatigue (Abdessemed et al., 1999; Baker, 2003; Tesch, Colliander and Kaiser, 1986).

Finally, given that the work was chunked into smaller sets and a greater frequency of rest periods in the ISRV loading scheme, it may be speculated that this scheme resulted in less vasoconstriction of the working muscles than the

CONT and ISRR loading schemes. In turn, if the ISRV loading scheme resulted in less vasoconstriction, it may be speculated that this loading scheme may be more appropriate, and safer, for populations susceptible to high blood pressure (hypertension). It may also be speculated that less vasoconstriction may result in less muscle hypoxia and / or anoxia, potentially minimising the fast to slow twitch fibre type transformations previously observed during resistance training (Friedmann et al., 2002; Sale, MacDougall, Jacobs and Garner, 1990).

It must be remembered that these results represent group means of the acute kinematic, kinetic and blood lactate responses to the different loading schemes and so should be interpreted with caution. The results of this study do not represent individual responses and do not offer insight into the longitudinal effects of training with intra-set rest loading schemes. However, it would seem that further investigation into the efficacy of intra-set rest loading protocols may be warranted. Such investigations may also enhance scientific understanding of rest and its influence on maximal strength and power development. It is recommended that such studies employ larger subject numbers and include a wider range of metabolic and hormonal markers than this study.

ACKNOWLEDGEMENTS

This project was supported by funding supplied by the Auckland University of Technology. Ethical approval was provided by the Human Subject Ethics Committee of the Auckland University of Technology, 31st May 2004 – ethics number 04/27.

CHAPTER FOUR: SUMMARY

SUMMARY

Through critically examining the literature in this area it is evident that there is a lack of scientific understanding regarding the effect of different rest periods on the development of strength and power. Given the importance of strength and power in everyday activities and athletic performance, the lack of understanding in this area is astounding. Previous research into the effect of rest on strength and power adaptation is plagued with methodological inconsistencies, between and within these studies, rendering the results incomparable and inferences about the effect of different rest periods problematic. To our knowledge there is no conclusive empirical evidence regarding the optimal inter-set rest period for strength and power adaptation and / or justifying the adoption of the recommendations disseminated to students, athletes, coaches and other health professionals through textbooks, coaching manuals and review articles. These recommendations, on which many health and sport professionals have based their practice, appear to be based on anecdotal evidence, are completely unsupported by scientific enquiry, or are based on inconclusive research or misguided interpretations.

While continuous loading schemes with inter-set rest periods of particular durations have been traditionally prescribed during resistance exercise, there does not appear to be any conclusive empirical evidence to suggest that this method and the previously specified rest durations are optimal for the development of maximal strength and power. Intra-set rest loading schemes,

which distribute the rest within the training set thereby increasing the frequency of rest during the session, have also been investigated as an alternative loading scheme however the efficacy of adopting such practice is currently unknown.

During our experimental investigation we examined the acute kinematic, kinetic and blood lactate responses to continuous and intra-set rest loading schemes. It was observed that manipulating the rest period, increasing the frequency and decreasing the length of each rest period, did not significantly influence the kinematics or kinetics associated with resistance training when the load, training volume and total rest time were equated. However, manipulating the rest in this way did result in lower post-exercise blood lactate accumulation. It was also observed that manipulating the rest in this manner allowed the subjects to perform a greater number of repetitions than during the CONT loading scheme when the load and rest time only were equated (ISRR).

Given these results, it would seem that intra-set rest loading schemes can provide an additional method for manipulating the training variables to alter the kinematics and kinetics of resistance training. Further it may be speculated that the repeated application of the ISRR loading scheme may provide a greater stimulus for the development of maximal strength, hypertrophy and power as greater time under tension, mean force, impulse, mean power and work was associated with this loading scheme. Similarly it may be speculated that the repeated application of the ISRV loading scheme may provide an alternative method of training for the development of muscular power, and provide a safer alternative for populations more susceptible to injury or medical conditions.

It must be remembered that these results represent group means of the acute kinematic, kinetic and blood lactate responses to the different rest protocols and so should be interpreted with caution. The results of this study do not represent individual responses to the loading schemes investigated and do not offer insights into the effect of longitudinal applications of intra-set rest loading. However, these findings do suggest that further investigations into the efficacy of intra-set rest loading schemes may be warranted. It is thought that such investigations may also enhance scientific understanding regarding the influence of rest on the development of maximal strength and power. It is recommended that such studies employ a larger number of subjects and examine a wider range of metabolic and hormonal markers than this study.

RECOMMENDATIONS

It is apparent that there are a number of areas requiring further research to improve scientific understanding of the effect of rest and the efficacy of intra-set rest loading. Further acute and longitudinal research should be conducted investigating the influence of different rest periods on neuronal strength, hypertrophy and power adaptation. To enhance scientific understanding in this area, it is recommended that such research carefully control for training load, tempo and volume while manipulating the rest interval. It is also recommended that such research employ isoinertial training methods as this mode of dynamometry more accurately reflects the movement patterns (e.g. the influences of acceleration and deceleration, the coupling of eccentric and

concentric contractions, etc.) of everyday activity, sporting performance and resistance training.

Future research should also be conducted to further investigate the mechanical, metabolic and hormonal responses (acute and longitudinal) to different rest intervals and loading schemes. Investigations involving a wider range of metabolic responses to resistance training schemes will greatly enhance scientific understanding in this area. Such research should, again, carefully control for training load, tempo, and volume and employ isoinertial training techniques.

Finally, it is recommended that further research, acute and longitudinal, be conducted into intra-set rest loading schemes to investigate the efficacy of training with such schemes and to investigate different intra-set rest loading scheme configurations. Ideally such research would investigate a wide range of the kinematic, kinetic, metabolic and hormonal responses to continuous and intra-set rest loading or investigate the morphological and neural adaptations associated with longitudinal application of these loading schemes.

REFERENCES

- Abdessemed, D., Duche, P., Hautier, C., & Bedu, M. (1999). Effect of recovery duration on muscular power and blood lactate during the bench press exercise. *International Journal of Sports Medicine*, 20, 368-373.
- Abernethy, P., Wilson, G., & Logan, P. (1995). Strength and power assessment: Issues, controversies and challenges. *Sports Medicine*, 19(6), 402-417.
- Anderson, T., & Kearney, J. T. (1982). Effects of three resistance training programs on muscular strength and absolute and relative endurance. *Research Quarterly for Exercise and Sport*, 53(1), 1-7.
- Baechle, T. R., & Earle, R. W. (2000). *Essentials of strength training and conditioning*. Champaign, Illinois: Human Kinetics.
- Baker, D. (2003). Acute negative effect of a hypertrophy-oriented training bout on subsequent upper-body power output. *Journal of Strength and Conditioning Research*, 17(3), 527-530.
- Berg, M. (2003). Rest-pause for growth: new muscle gain is just a brief pause away with this powerful training technique. (Smart Training). *Men's Fitness*, May.
- Bloomer, R. J., & Ives, J. C. (2000). Varying neural and hypertrophic influences in a strength program. *Strength and Conditioning Journal*, 22(2), 30-35.
- Bogdanis, G. C., Nevill, M. E., Lakomy, H. K. A., & Boobis, L. H. (1998). Power output and muscle metabolism during and following recovery from 10 and 20 s of maximal sprint exercise in humans. *Acta Physiologica Scandinavica*, 163(3), 261-272.

Bompa, T. O., & Cornacchia, L. J. (1998). *Serious strength training: Periodization for building muscle power and mass*. Champaign, Illinois: Human Kinetics.

Bosco, C., Cardinale, M., & Tsarpela, O. (1999). Influence of vibration on mechanical power and electromyogram activity in human arm flexor muscles. *European Journal of Applied Physiology*, 79, 306-311.

Brandenburg, J. P., & Docherty, D. (2002). The effects of accentuated eccentric loading on strength, muscle hypertrophy, and neural adaptations in trained individuals. *Journal of Strength and Conditioning Research*, 16(1), 25-32.

Brown, A. B., McCartney, N., & Sale, D. B. (1990). Positive adaptations to weight-lifting training in the elderly. *Journal of Applied Physiology*, 69(5), 1725-1733.

Byrd, R., Centry, R., & Boatwright, D. (1988). Effect of inter-repetition rest intervals in circuit weight training on PWC₁₇₀ during arm-kranking exercise. *Journal of Sports Medicine and Physical Fitness*, 28, 336-40.

Calder, A. W., Chilibeck, P. D., Webber, C. E., & Sale, D. G. (1994). Comparison of whole and split weight training routines in young women. *Canadian Journal of Applied Physiology*, 19(2), 185 - 199.

Campos, G. E. R., Luecke, T. J., Wendeln, H. K., Toma, K., Hagerman, F. C., Murray, T. F., Ragg, K. E., Ratamess, N. A., Kraemer, W. J., & Staron, R. S. (2002). Muscular adaptations in response to three different resistance-training regimens: Specificity of repetition maximum training zones. *European Journal of Applied Physiology*, 88, 50-60.

Carey Smith, R., & Rutherford, O. M. (1995). The role of metabolites in strength training. I. A comparison of eccentric and concentric contractions. *European Journal of Applied Physiology*, 71, 332-336.

Carpinelli, R. N., Otto, R. M., & Winett, R. A. (2004). A critical analysis of the ACSM position stand on resistance training: Insufficient evidence to support recommended training protocols. *Journal of Exercise Physiology*, 7(3), 1-60.

Chestnut, J. L., & Docherty, D. (1999). The effects of 4 and 10 repetition maximum weight-training protocols on neuromuscular adaptations in untrained men. *Journal of Strength and Conditioning Research*, 13(4), 353-359.

Consitt, L. A., Copeland, J. L., & Tremblay, M. S. (2002). Endogenous anabolic hormone responses to endurance versus resistance exercise and training in women. *Sports Medicine*, 32(1), 1-22.

Crewther, B., Cronin, J., & Cook, C. (In Press). Possible stimuli for strength and power adaptation: Part 2: Hormonal and metabolic stimuli. *Sports Medicine*.

Crewther, B. T. (2004). *The mechanical, hormonal and metabolic responses to two resistance loading schemes*. Unpublished master's thesis, Auckland University of Technology, Auckland, New Zealand.

Cronin, J., & Owen, G. J. (2004). Upper-body strength and power assessment in women using a chest pass. *Journal of Strength and Conditioning Research*, 18(3), 401-404.

Cronin, J. B. (1996). Strength training for sport part 1: Classifying strength and strength training methods. *The New Zealand Coach, Summer*, 8-9.

Cronin, J. B., McNair, P. J., & Marshall, R. N. (2000). The role of maximal strength and load on initial power production. *Medicine and Science in Sports and Exercise*, 32(10), 1763-1769.

Cronin, J. B., McNair, P. J., & Marshall, R. N. (2002). Is velocity-specific strength training important in improving functional performance? *Journal of Sports Medicine and Physical Fitness*, 42(3), 267-273.

Deschenes, M. R., Kraemer, W. J., Maresh, C. M., & Crivello, J. F. (1991). Exercise induced hormonal changes and their effects upon skeletal muscle tissue. *Sports Medicine*, 12(2), 80-93.

Dowson, M. (1996). *The fitness advisor*. Auckland: Harper Collins.

Enoka, R. M. (2002). *Neuromechanics of human movement*. Champaign, Illinois: Human Kinetics.

Folland, J. P., Irish, C. S., Roberts, J. C., Tarr, J. E., & Jones, D. A. (2002). Fatigue is not a necessary stimulus for strength gains during resistance training. *British Journal of Sports Medicine*, 36(5), 370-374.

Friedmann, B., Borisch, S., Kucera, K., Muller, H., Erb, G., Richter, G., & Bartsch, P. (2002). Effects of strength endurance training in normobaric hypoxia on muscle cross sectional area, strength endurance capacity and maximal strength. *International Journal of Sports Medicine*, 23(S2), S78.

Hamill, J., & Knutzen, K. M. (1995). *Biomechanical basis of human movement*. Pennsylvania: Williams and Wilkins.

Jones, K., Bishop, P., Hunter, G., & Fleisig, G. (2001). The effects of varying resistance-training loads on intermediate- and high-velocity-specific adaptations. *Journal of Strength and Conditioning Research*, 15(3), 349-356.

Knuttgen, H. G. (2003). What is exercise? A primer for practitioners. *The Physician and Sportsmedicine*, 31(3).

Komi, P. V., & Hakkinen, K. (1988). Strength and power. In A. Dirix, H. G. Knuttgen and K. Tittel (Eds.), *The Olympic book of sports medicine* (pp. 181-193). Boston: Blackwell Scientific.

Kraemer, W. (1992). Influence of the endocrine system on resistance training adaptations. *National Strength and Conditioning Association*, 14(2), 47-54.

Kraemer, W. J. (1997). A series of studies - The physiological basis for strength training in American Football: Fact over philosophy. *Journal of Strength and Conditioning Research*, 11(3), 131-142.

Kraemer, W. J., Adams, K., Cafarelli, E., Dudley, G. A., Dooly, C., Feigenbaum, M. S., Fleck, S. J., Franklin, B., Fry, A. C., Hoffman, J. R., Newton, R. U., Potteiger, J., Stone, M. H., Ratamess, N. A., & Triplett-McBride, T. (2002). Progression models in resistance training for healthy athletes. *Medicine and Science in Sports and Exercise*, 34(2), 364-380.

Kraemer, W. J., Hakkinen, K., Triplett-McBride, N. T., Fry, A. C., Koziris, L. P., Ratamess, N. A., Bauer, J. E., Volek, J. S., McConnell, T., Newton, R. U., Gordon, S. E., Cummings, D., Hauth, J., Pullo, F., Lynch, J. M., Mazzetti, S. A., & Knuttgen, H. G. (2003). Physiological changes with periodized resistance training in women tennis players. *Medicine and Science in Sports and Exercise*, 35(1), 157-168.

Kraemer, W. J., Marchitelli, L., Gordon, S. E., Harman, E., Dziados, J. E., Mello, R., Frykman, P., McCurry, D., & Fleck, S. J. (1990). Hormonal and growth factor responses to heavy resistance exercise protocols. *Journal of Applied Physiology*, 69(4), 1442-1450.

Kraemer, W. J., Noble, B. J., Clark, M. J., & Culver, B. W. (1987). Physiologic responses to heavy-resistance exercise with very short rest periods. *International Journal of Sports Medicine*, 8, 247-252.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: Progression and exercise prescription. *Medicine and Science in Sports and Exercise*, 36(4), 674-688.

Lambert, C. P., & Flynn, M. G. (2002). Fatigue during high-intensity intermittent exercise. *Sports Medicine*, 32(8), 511-522.

Larson, G. D., & Potteiger, J. A. (1997). A comparison of three different rest intervals between multiple squat bouts. *Journal of Strength and Conditioning Research*, *11*(2), 115-118.

Lawton, T., Cronin, J., Drinkwater, E., Lindsell, R., & Pyne, D. (2004). The effect of continuous repetition training and intra-set rest training on bench press strength and power. *Journal of Sports Medicine and Physical Fitness*, *44*(4), 361-367.

Lawton, T., Cronin, J., & Lindsell, R. (In Press). Effect of inter-repetition rest intervals on weight training repetition power output. *Journal of Strength and Conditioning Research*.

Linnamo, V., Hakkinen, K., & Komi, P. V. (1998). Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *European Journal of Applied Physiology*, *77*, 176-181.

MacDougall, J. D. (1992). Hypertrophy or hyperplasia. In P. V. Komi (Ed.), *Strength and power in sport* (pp. 230-238). Oxford: Blackwell Scientific Publications.

Matuszak, M. E., Fry, A. C., Weiss, L. W., Ireland, T. R., & McKnight, M. M. (2003). Effect of rest interval length on repeated 1 repetition maximum back squats. *Journal of Strength and Conditioning Research*, *17*(4), 634-637.

Mazzetti, S. A., Kraemer, W. J., Volek, J. S., Duncan, N. D., Ratamess, N. A., Gomez, A. L., Newton, R. U., Hakkinen, K., & Fleck, S. J. (2000). The influence of direct supervision of resistance training on strength performance. *Medicine and Science in Sports and Exercise*, *32*(6), 1175-1184.

McDonagh, M. J. N., & Davies, C. T. M. (1984). Adaptive response of mammalian skeletal muscle to exercise with high loads. *European Journal of Applied Physiology*, *52*, 139-155.

McEvoy, K. P., & Newton, R. U. (1998). Baseball throwing speed and base running speed: The effects of ballistic resistance training. *Journal of Strength and Conditioning Research*, 12(4), 216-221.

Moritani, T. (1992). Time course of adaptations during strength and power training. In P. V. Komi (Ed.), *Strength and power in sport* (pp. 266-278). Boston: Blackwell Scientific Publications.

Moss, B. M., Refsnes, P. E., Abildgaard, A., Nicolaysen, K., & Jensen, J. (1997). Effects of maximal effort strength training with different loads on dynamic strength, cross-sectional area, load-power and load-velocity relationships. *European Journal of Applied Physiology*, 75, 193-199.

Newton, R. U., Kraemer, W. J., Hakkinen, K., Humphries, B. J., & Murphy, A. J. (1996). Kinematics, kinetics and muscle activation during explosive upper body movements. *Journal of Applied Biomechanics*, 12, 31-43.

Newton, R. U., Murphy, A. J., Humphries, B. J., Wilson, G. J., Kraemer, W. J., & Hakkinen, K. (1997). 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*, 75, 333-342.

Nigg, B. M., MacIntosh, B. R., & Mester, J. (2000). *Biomechanics and biology of movement*. Champaign, Illinois: Human Kinetics.

O'Hagan, F. T., Sale, D. G., MacDougall, J. D., & Garner, S. H. (1995). Comparative effectiveness of accommodating and weight resistance training modes. *Medicine and Science in Sports and Exercise*, 27(8), 1210-1219.

Ostrowski, K. J., Wilson, G. J., Weatherby, R., Murphy, P. W., & Lyttle, A. D. (1997). The effect of weight training volume on hormonal output and muscular size and function. *Journal of Strength and Conditioning Research*, 11(1), 148-154.

- Parcell, A. C., Sawyer, R. D., Tricoli, V. A., & Chinevere, T. D. (2002). Minimum rest period for strength recovery during a common isokinetic testing protocol. *Medicine and Science in Sports and Exercise*, 34(6), 1018-1022.
- Pauletto, B. (1986). Rest and recuperation. *National Strength and Conditioning Association Journal*, 8(3), 52-53.
- Pearson, D. R., & Costill, D. L. (1988). The effects of constant external resistance exercise and isokinetic exercise training on work-induced hypertrophy. *Journal of Applied Sport Science Research*, 2(3), 39-41.
- Pierce, K. C., Rozenek, R., & Stone, M. E. (1993). Effects of high volume weight training on lactate, heart rate, and perceived exertion. *Journal of Strength and Conditioning Research*, 7(4), 211-215.
- Pincivero, D. M., Gear, W. S., Moyna, N. M., & Robertson, R. J. (1999). The effects of rest interval on quadriceps torque and perceived exertion in healthy males. *Journal of Sports Medicine and Physical Fitness*, 39, 294-299.
- Plisk, S. S. (2001). Muscular strength and stamina. In B. Foran (Ed.), *High-performance sports conditioning* (pp. 63-82). Champaign, Illinois: Human Kinetics.
- Poliquin, C. (1991). Training for improving relative strength. *Science Periodical on Research and Technology in Sport*, 11(7).
- Pritzlaff-Roy, C. J., Widemen, L., Weltman, J. Y., Abbott, R., Gutgesell, M., Hartman, M. L., Veldhuis, J. D., & Weltman, A. (2002). Gender governs the relationship between exercise intensity and growth hormone release in young adults. *Journal of Applied Physiology*, 92, 2053-2060.
- Read, M. M., & Cisar, C. (2001). The influence of varied rest interval lengths on depth jump performance. *Journal of Strength and Conditioning Research*, 15(3), 279-283.

Rennie, M. J. (2003). Claims for the anabolic effects of growth hormone: A case of the Emperor's new clothes? *British Journal of Sports Medicine*, 37, 100-105.

Robinson, J. M., Stone, M. H., Johnson, R. L., Penland, C. M., Warren, B. J., & Lewis, R. D. (1995). Effects of different weight training exercise / rest intervals on strength, power, and high intensity exercise endurance. *Journal of Strength and Conditioning Research*, 9(4), 216-221.

Rooney, K. J., Herbert, R. D., & Balnave, R. J. (1994). Fatigue contributes to the strength training stimulus. *Medicine and Science in Sports and Exercise*, 26(9), 1160-1164.

Rowland, T. W., Rambusch, J. M., Staab, J. S., Unnithan, V. B., & Siconolfi, S. F. (1993). Accuracy of physical working capacity (PWC₁₇₀) in estimating aerobic fitness in children. *Journal of Sports Medicine and Physical Fitness*, 33(2), 184-188.

Sale, D. G. (2002). Postactivation potentiation: Role in human performance. *Exercise and Sport Science Reviews*, 30(3), 138-143.

Sale, D. G., MacDougall, J. D., Jacobs, I., & Garner, S. H. (1990). Interaction between concurrent strength and endurance training. *Journal of Applied Physiology*, 68(1), 260-270.

Schlumberger, A., Stec, J., & Schmidtbleicher, D. (2001). Single- vs. multiple-set strength training in women. *Journal of Strength and Conditioning Research*, 15(3), 284-289.

Schmidtbleicher, D. (1992). Training for power events. In P. V. Komi (Ed.), *Strength and power in sport* (pp. 381-395). Champaign, Illinois: Human Kinetics.

Schott, J., McCully, K., & Rutherford, O. M. (1995). The role of metabolites in strength training: II. Short versus long isometric contractions. *European Journal of Applied Physiology*, 71, 337-341.

Sewall, L. P., & Lander, J. E. (1991). The effects of rest on maximal efforts in the squat and bench press. *Journal of Applied Sport Science Research*, 5(2), 96-99.

Stone, M. H., Plisk, S. S., Stone, M. E., Schilling, B. K., O'Bryant, H. S., & Pierce, K. C. (1998). Athletic performance development: Volume load - 1 set vs multiple sets, training velocity and training variation. *Strength and Conditioning*, Dec, 22-31.

Takarada, Y., Sato, K., & Ishii, N. (2002). Effects of resistance exercise combined with vascular occlusion on muscle function in athletes. *European Journal of Applied Physiology*, 86, 308-314.

Tesch, P. (1987). Acute and long - term metabolic changes consequent to heavy - resistance exercise. *Medicine and Sport Science*, 26, 67 - 89.

Tesch, P. A. (1992). Training for bodybuilding. In P. V. Komi (Ed.), *Strength and power in sport* (pp. Champaign, Illinois: Human Kinetics).

Tesch, P. A., Colliander, E. B., & Kaiser, P. (1986). Muscle metabolism during intense, heavy-resistance exercise. *European Journal of Applied Physiology*, 55(4), 362-366.

Tesch, P. A., Ploutz-Snyder, L. L., Ystrom, L., Castro, M. J., & Dudley, G. A. (1998). Skeletal muscle glycogen loss evoked by resistance exercise. *Journal of Strength and Conditioning Research*, 12(2), 67-73.

Villani, R. R. (1987). The effects of progressive resistance training on skeletal muscle protein degradation in man. *Australian Journal of Science and Medicine in Sport*, 19(3), 14-17.

Wagner, L. L., Evans, S. A., Weir, J. P., Housh, T. J., & Johnson, G. O. (1992). The effect of grip width on bench press performance. *International Journal of Sport Biomechanics*, 8, 1-10.

Weir, J. P., Wagner, L. L., & Housh, T. J. (1994). The effect of rest interval length on repeated maximal bench presses. *Journal of Strength and Conditioning Research*, 8(1), 58-60.

Weiss, L. W. (1991). The obtuse nature of muscular strength: The contribution of rest to its development and expression. *Journal of Applied Sport Science Research*, 5(4), 219-227.

Wilmore, J. H., & Costill, D. L. (1999). *Physiology of sport and exercise*. Champaign, Illinois: Human Kinetics.

Wilson, G. (1999). Resistance training guidelines: Optimal rest periods. *Strength and Conditioning Coach*, 7(5), 3-5.

Wilson, G., Newton, R. U., Murphy, A. J., & Humphries, B. J. (1993). The optimal training load for the development of dynamic athletic performance. *Medicine and Science in Sports and Exercise*, 25(11), 1279-1286.

Wood, R. (2004). *Endurance tests: The aerobic energy system: PWC₁₇₀ test*. Retrieved June 23, 2004, from <http://www.topendsports.com/testing/tests/PWC170.htm>

Woods, S., Bridge, T., Nelson, D., Risse, K., & Pincivero, D. M. (2004). The effects of rest interval length on ratings of perceived exertion during dynamic knee extension exercise. *Journal of Strength and Conditioning Research*, 18(3), 540-545.

Young, W. B., & Bilby, G. E. (1993). The effect of voluntary effort to influence speed of contraction on strength, muscular power, and hypertrophy development. *Journal of Strength and Conditioning Research*, 7(3), 172-178.

Zatsiorsky, V. M. (1995). *Science and practice of strength training*. Champaign, Illinois: Human Kinetics.

APPENDICES

Appendix 1: Blood lactate responses to the continuous and intra-set rest loading schemes

Blood lactate response to the continuous scheme

	Raw data Mean (SD)	Change from pre (raw)	Change from pre (%)	P value
Pre	1.65 (0.27)	-	-	-
P0	4.95 (0.38)	3.30	200	0.002
P5	4.47 (1.79)	2.82	170.9	0.002
P15	2.64 (0.81)	0.99	60	0.020
P30	1.70 (0.59)	0.05	3	0.892

Blood lactate response to the ISRV scheme

	Raw data Mean (SD)	Change from pre (raw)	Change from pre (%)	P value
Pre	1.99 (0.27)	-	-	-
P0	4.23 (2.05)	2.24	112.6	0.010
P5	2.98 (1.40)	0.99	49.7	0.060
P15	1.98 (0.99)	-0.01	-0.5	0.852
P30	1.76 (0.67)	-0.23	-11.6	0.186

Blood lactate response to the ISRR scheme

	Raw data Mean (SD)	Change from pre (raw)	Change from pre (%)	P value
Pre	2.04 (0.54)	-	-	-
P0	6.42 (1.41)	4.38	214.7	<0.001
P5	6.07 (1.56)	4.03	197.5	<0.001
P15	3.44 (1.19)	1.4	68.6	0.017
P30	2.17 (0.75)	0.13	6.4	0.778

NOTE: The P values reported are for the comparison between the post-exercise time point and the pre-exercise baseline measure as determined through a one-way repeated measures analysis of variance (ANOVA).

Appendix 2: Participant Information Sheet



Project Title: **Mechanical and metabolic profiles of continuous and intra-set rest strength training.**

Project Supervisor: **Dr. John Cronin**

Researcher: **Jamie Denton**

You are invited to participate in a study investigating the acute effects of continuous and intra-set rest period training protocols. This study is being undertaken as part of a Masters of Health Science qualification. Participation is completely voluntary and you may withdraw at any stage without giving a reason or being disadvantaged.

What is the purpose of the study?

Rest periods are prescribed, during resistance training, to allow recovery from fatigue and to promote the desired training adaptation. Traditionally, resistance training programming has implemented inter-set, or between set, rest periods. Recently, however, intra-set, or within set, rest periods have been developed. The effects of intra-set rest periods have yet to be fully established. Therefore, this study will examine the acute mechanical and metabolic responses to continuous and intra-set rest period training equated by total time, volume or time under tension.

Can I join the study?

If you have at least 12 months weight training experience, no injuries and do not suffer from high blood pressure then you are eligible to participate in this study.

Costs of participating?

Subjects will not incur any monetary costs participating in this study. Subjects will be required to attend four assessment sessions (1 x 30; 3 x 90 minutes).

What happens in the study?

This project will be performed over four testing occasions during the hours of 9.00am to 5.00pm. During the first session each subject's 6RM (repetition maximum) will be determined for the bench press on the Smith machine. Subjects will then be asked to perform three different training protocols of varying rest period types and lengths during subsequent sessions, followed by five finger-prick blood samples to assess the metabolic response of various physiological measures to each protocol. Adequate rest (48-72 hours) will be provided between each testing session.

What are the benefits?

These results will improve our understanding of the effects of continuous and intra-set rest periods during resistance training and provide prescriptive information for assigning rest periods during training. An

additional benefit will be the validation of equipment and procedures employed for future research. Subjects will gain strength assessment information for the upper body (1RM).

What are the discomforts and risks?

The risks involved in this study are minimal. Subjects may experience mild muscular discomfort from the resistance protocols, and mild discomfort from the finger-prick blood sampling procedures. If an injury occurs due to unforeseen circumstances, you will receive immediate attention from the AUT physiotherapists, located thirty metres from the testing premises.

What compensation is available for injury or negligence?

The researcher, AUT or the principal supervisor will not be responsible for any monetary loss incurred in the unlikely event of injury. The ACC system, with its limitations, will provide standard cover if participants are injured.

How is my privacy protected?

All records will be kept in a locked limited access cabinet. Data will be treated as confidential and will be used only for the purpose of this study.

Results

The results of this project will be published in a scientific journal and presented at a national or international conference.

Time To Consider Invitation

You will be given time (14 days) to consider this invitation.

Participant Concerns

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor. Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEK, Madeline Banda, madeline.banda@aut.ac.nz, 917 9999 ext 8044.

Project Supervisor

Dr. John Cronin
Deputy Director of Sport Science Research
Division of Sport and Recreation
Auckland University of Technology
Phone 917 9999 ext 7353

Principal Investigator

Mr Jamie Denton
Division of Sport and Recreation
Auckland University of Technology
Phone 917 9999 ext 7119
jamie.denton@aut.ac.nz

**Approved by the Auckland University of Technology Ethics
Committee: 31/05/04
AUTEK Reference number 04/27**



Consent to Participation in Research

Title of Project: **The mechanical and metabolic profiles of continuous and intra-set rest period training**

Project Supervisor: **Dr. John Cronin**

Researcher: **Jamie Denton**

- I have read and understood the information provided about this research project (Information Sheet dated 31 May 2004.)
- I have had an opportunity to ask questions and to have them answered.
- I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- If I withdraw, I understand that all my data will be destroyed.
- I agree to take part in this research.
- I wish to receive a copy of the report from the research.
- I acknowledge that I have at least 12 months weight training experience.
- I do not have any current injuries, or medical conditions (including high blood pressure) that would exclude me from participation.

Participant signature:

Participant name:

Participant Contact Details (if appropriate):

.....
.....
.....

Date:

**Approved by the Auckland University of Technology Ethics Committee on 15/03/04
AUTEC Reference number 04/27**

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

Appendix 4: Ethics Approval Sheet

M E M O R A N D U M



Student Services Group – Academic Services

To: John Cronin
From: Madeline Banda
Date: 31 May 2004
Subject: 04/27 The mechanical, hormonal and metabolic profiles of continuous and intra-set rest strength training

Dear John

Thank you for providing amendment and clarification of your ethics application as requested by AUTEK.

Your application was approved for a period of two years until 31 May 2006.

You are required to submit the following to AUTEK:

- A brief annual progress report indicating compliance with the ethical approval given.
- A brief statement on the status of the project at the end of the period of approval or on completion of the project, whichever comes sooner.
- A request for renewal of approval if the project has not been completed by the end of the period of approval.

Please note that the Committee grants ethical approval only. If management approval from an institution/organisation is required, it is your responsibility to obtain this.

The Committee wishes you well with your research.

Please include the application number and study title in all correspondence and telephone queries.

Yours sincerely

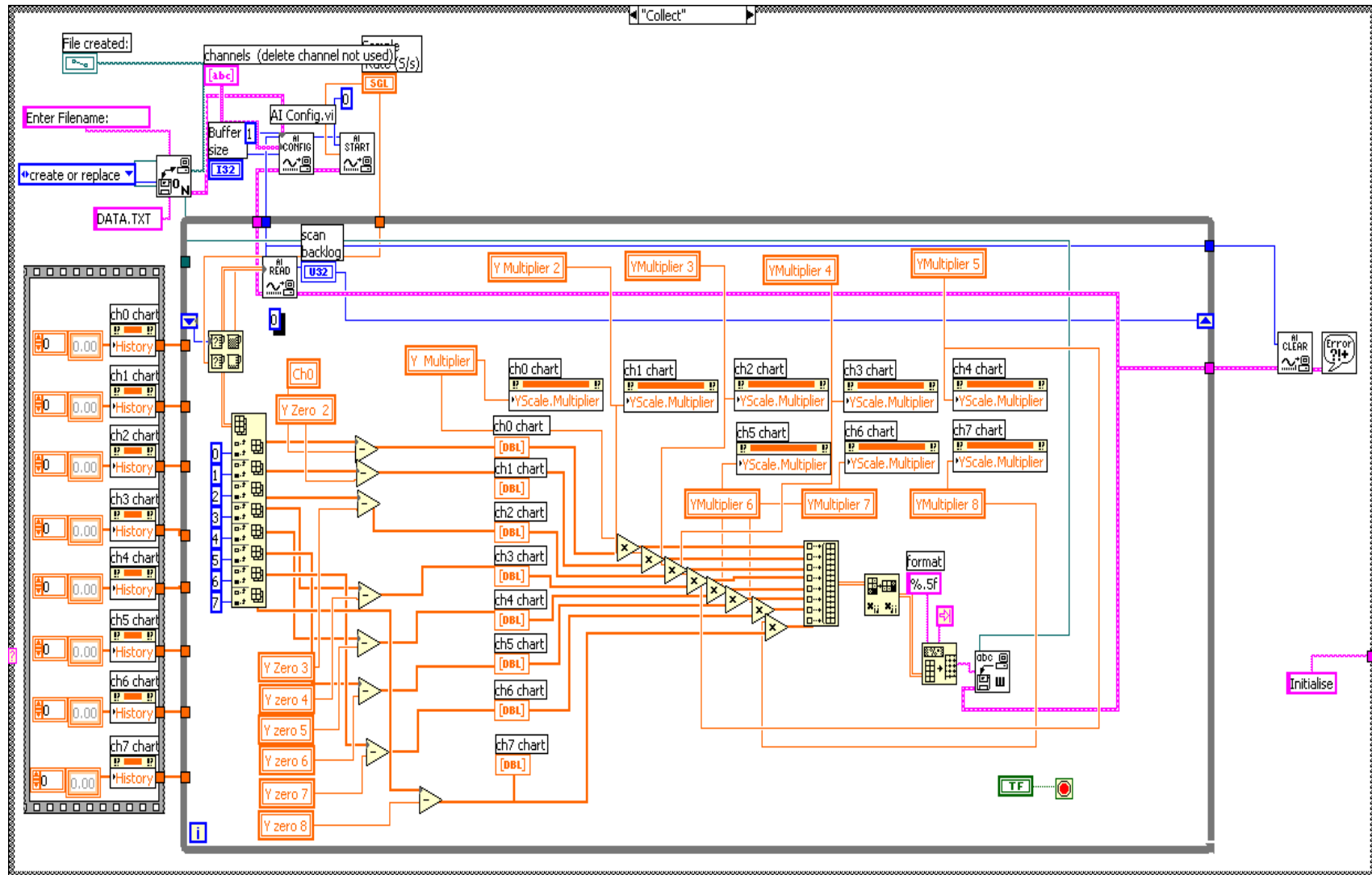
A handwritten signature in black ink, appearing to read 'M. Banda', is written over a light blue horizontal line.

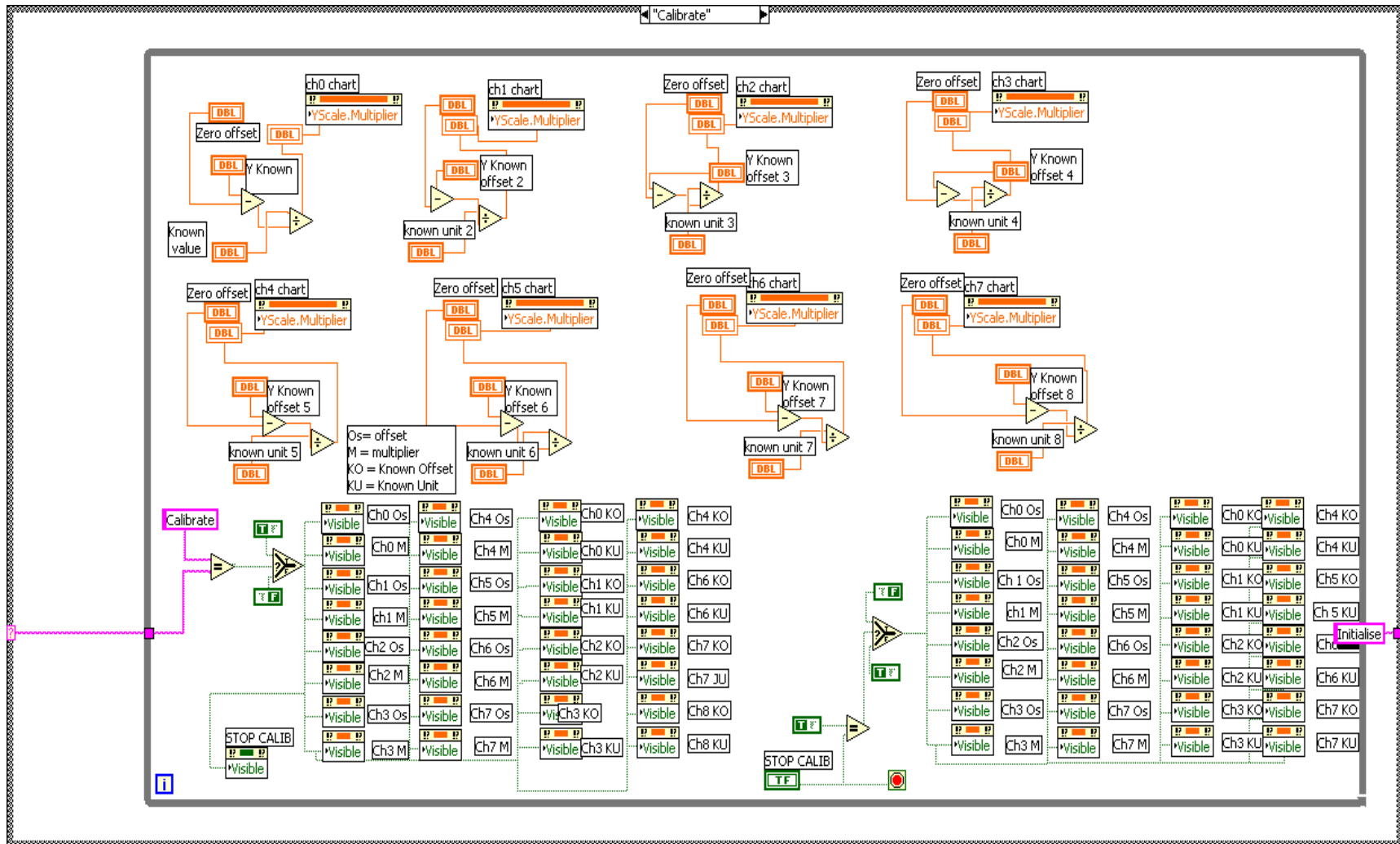
Madeline Banda
Executive Secretary
AUTEK
CC: 0005333 Jamie Denton

Appendix 5: LabView Data Collection Program (Front Panel)



Appendix 6: LabView Data Collection Program (Back Panel)





Appendix 7: LabView Data Analysis Program (Front Panel)

Linear Displacement Analysis Programme

mass (kg)

File Name

Sample Rate (Hz)

Save Displacement Data As

Row Column

First Phase
 ECC CONC

Start

End

Seconds to remove spike at start

Remove spike at end

Low Cutoff

High Cutoff

Disp Calib (mV/V/mm)

Vel Calib (mV/mm/sec)

Start/End %

Start conc count

Start ecc count

Disp Supply Voltage

dt

Start conc phase (s)

<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>
------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------

Start ecc phase (s)

<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>
------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------

Conc Phase duration (s)

<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>
------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------

Ecc Phase duration (s)

<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>	<input type="text" value="0.000"/>
------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------	------------------------------------

Analog Input Setup

Channels	Gains (Diff Only)
<input type="text" value="7 SE (+/-10V)"/> <input type="button" value="v"/>	<input type="text" value="1 (+/-20V)"/> <input type="button" value="v"/>
<input type="text" value="0-1 Diff"/> <input type="button" value="v"/>	<input type="text" value="1 (+/-20V)"/> <input type="button" value="v"/>
<input type="text" value="0 SE (+/-10V)"/> <input type="button" value="v"/>	<input type="text" value="1 (+/-20V)"/> <input type="button" value="v"/>
<input type="text" value="0 SE (+/-10V)"/> <input type="button" value="v"/>	<input type="text" value="1 (+/-20V)"/> <input type="button" value="v"/>

Number of Channels (1,2,4)

All differentiated data (graphed)

<input type="text" value="0"/>	<input type="text" value="-20.03"/>	<input type="text" value="2109.1"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="9.81"/>	<input type="text" value="-42245"/>
<input type="text" value="0"/>	<input type="text" value="-20.03"/>	<input type="text" value="2109.1"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="9.81"/>	<input type="text" value="-42245"/>
<input type="text" value="0"/>	<input type="text" value="-20.03"/>	<input type="text" value="2109.1"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="9.81"/>	<input type="text" value="-42245"/>

Conc Phase Variables

<input type="text" value="0"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>
--------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------

Ecc Phase Variables

<input type="text" value="0"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>	<input type="text" value="0.00"/>
--------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------	-----------------------------------

Order of Output

- Force Max
- Force Mean
- Impulse
- Power Max
- Power Mean
- Velocity Max
- Velocity Mean
- Work
- Work (mean f x peak d)
- Acceleration Max
- Acceleration Mean

Appendix 8: Mathematical Formulae Used To Derive Kinematic And Kinetic Values From Displacement Data

Variable	Units	Formula
Acceleration	Meters per second ² (m.s ⁻²)	$a = \Delta v / \Delta t$ (Acceleration = change in velocity / change in time)
Force	Newtons (N)	$F = m * a$ (Force = mass * acceleration)
Impulse	Newton seconds (N.s)	$I = F_{\text{average}} * \Delta t$ (Impulse = average force * change in time)
Power	Watts (W)	$P = F * v$ (Power = force * velocity)
Velocity	Meters per second (m.s ⁻¹)	$v = \Delta d / \Delta t$ (Velocity = change in displacement / change in time)
Work	Joules (J)	$W = F_{\text{average}} * d$ (Work = average force * displacement)

From: Hamill and Knutzen, 1995