A comparison between a traditionally periodised programme and a load autoregulated periodised programme for maximal strength gain in the squat, bench press, and deadlift in weight-trained males

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Abstract

Background: Training towards the goal of improving maximal strength is commonly undertaken; particularly by athletes involved in contact sports, powerlifters, and recreational body builders. Multiple methods of programming exist, with autoregulated (AR) training being a popular topic within the training community. AR training involves day to day fluctuations in volume and/or intensity in order to accommodate the athlete's performance on a given day. This could potentially allow for greater gains in strength due to fine tuning of the fatigue -fitness interaction. However, scant research exists on AR training, with the vast majority being carried out on individuals during rehabilitation therapy.

Aim: To examine whether a load-autoregulated strength training programme is more effective in improving maximal strength in the squat, bench press, and dead lift than a traditionally periodised program, in experienced weight-trained individuals.

Methods: Eight healthy, recreationally trained males agreed to participate and completed this study. Each participant completed a traditionally (TD) programme and an AR programme in a randomised, cross-over design with a 2-week wash out period between. Each programme involved baseline one-repetition-maximum testing (1RM) in the barbell squat, bench press, and deadlift followed by eight weeks of training with subsequent 1RM testing. Following warm up, participants completed one set of as many repetitions as possible (AMRAP) at 85% of baseline 1RM, followed by subsequent working sets. 1RM Prediction equations were utilised in the AR training group to dictate load used in the working sets; whereas the TD groups subsequent sets were based on baseline 1RM.

Results: The squat, deadlift, and total improved significantly within each programme (all $p<0.05$), however no differences between programmes were present (all $p>0.05$). Bench press strength improvement was significantly greater in the TD programme (time x programme interaction $p<0.05$).

Conclusions: The present study found no differences in effectiveness of programmes at producing strength gain in the squat, deadlift, or total weight lifted. However the TD programme resulted in a greater improvement in bench press strength compared to AR. Future research would also involve auto-regulated volume, as well as ensuring matched cross over design, and ideally a use of more trained participants.

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Abbreviations

A

AR	Autoregulated
AKT	Protein kinase B
AMRAP	As many repetitions as possible

B

BP	Block periodisation
B1	Baseline testing one
B2	Baseline testing two

C

CNS	Central nervous system
CSA	Cross sectional area

D

DUP	Daily undulating periodisation

E

EIMD	Exercise-induced muscle damage
EMG	Electromyography
ES	Effect size

F

FP	Foot position
F1	Final testing one
F2	Final testing two

G

g	Gravitational acceleration

H

HR	Heart rate

K

kg	Kilograms

L

LP	Linear periodisation

M

mTOR	Mammalian target of rapamycin

N

NP	Non-periodised

R

RIR	Repetitions in reserve
RLP	Reverse linear periodisation
RPE	Rating of perceived exertion

T

TD	Traditionally periodised programme

U

UP	Undulating periodisation

W

WUP	Weekly undulating periodisation
W1T1	Week one trial one
W8T1	Week eight trial one

#

1RM	One repetition maximum
3x10	3 sets of 10 repetitions per set

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Chapter 1 – Introduction

Training towards the goal of improving maximal strength is commonly undertaken; particularly by athletes involved in contact sports, powerlifters, and recreational body builders. To achieve this, periodisation, the arrangement of training into periods known as macrocycles (six months to four years (e.g. the start of an Olympic cycle)), mesocycles (often one to three months), and microcycles (often one week long) (Helms, Fitschen, Aragon, Cronin, & Schoenfeld, 2015) is often used. Training variables such as volume, frequency, intensity, and exercise selection are arranged appropriately within periodised programmes so that continual progress, fatigue management, prevention of overtraining, and the display of particular fitness attributes at the desired time occur accordingly (Plisk & Stone, 2003).

The optimal method to promote maximal strength adaptation has been thoroughly researched with traditional linear periodisation (LP) often surpassing programmes which lack planned periodisation. This is likely due to the facilitation of greater intensity and volume without overtraining (Herrick & Stone, 1996; Rhea & Alderman, 2004) LP programmes typically follow a trend where the beginning of the training cycle has an emphasis on a higher volume of training with lower intensities and less sport-specific movements. This phase transitions into lower volume and higher intensity with inclusion of more sport-specific movements, and aims to peak an individual's performance at a pre-planned date (Berger, Harre, & Ritter, 1982). Conversely, reverse linear periodisation (RLP) commences with low training volume and high intensity before shifting towards a higher volume and lower intensity (Prestes, De Lima, Frollini, Donatto, & Conte, 2009a). Alternatively, undulating periodization (UP) commonly prescribed as weekly undulating periodisation (WUP) or daily undulating periodisation (DUP) exhibit more frequent fluctuations in volume and intensity throughout the training cycle and may be more effective in improving maximal strength than LP in trained individuals (Rhea, Ball, Phillips, & Burkett, 2002). Similarly to LP, average intensity in UP models often increases through the course of the training block, while average volume decreases (Harries, Lubans, & Callister, 2015b).

This can be useful in peaking performance while also maintaining certain fitness attributes gained in the earlier phases of the training cycle. Block periodisation (BP) has a similar structure to LP except that training is arranged into distinct blocks which have the goal of preparing the athlete for the subsequent block. For example, a rugby player's strength plan may be periodised by a muscular hypertrophy phase followed by a maximal strength phase, preceding development of sport-specific power (Bartolomei, Hoffman, Merni, & Stout, 2014). Finally, autoregulated (AR) training can adopt any of the underlying structures of the previously mentioned progression plans; however day to day fluctuations in volume and/or intensity are used to accommodate the athlete's performance on a given day. Strength can vary up to 10-20% on a day to day basis, resulting in a variable amount of repetitions when using a fixed percentage of 1RM (Poliquin, 1988). This may result in some trainings providing a sub-optimal stimulus; either utilisation of too high of a load, or too little for the strength capabilities of the day. This variability provides rationale for the use of AR training which could potentially allow for greater gains in strength due to fine tuning of the fatigue-fitness interaction. However, scant research exists on AR training, with the vast majority of it being performed on individuals who are undertaking rehabilitation therapy (Ardali, 2014; Horschig, Neff, & Serrano, 2014). More research is required to determine the efficacy of implementing AR techniques for athletes who require improvements in maximal strength.

Given the apparent lack of previous research into the effects of AR on strength development, this study will compare a traditionally periodised programme (TD) to an 8-week AR programme in a cross-over design. Both programmes will be linear in nature. The programmes differ in that the training load for the AR programme will be dictated by the individual’s strength on the day (as determined by a set of as many reps as possible (AMRAP) with 85% of baseline 1RM (repetition maximum)) whilst training load during TD will be entirely based on percentages derived from baseline 1RM. Participants with weight training experience will be recruited as this will help to protect against the initial neural adaptation that beginner’s experience; as this factor may impact the response seen in each training programme (Cissik, Hedrick, & Barnes, 2008).

Chapter 2 – Literature Review

The literature encompassing resistance training for strength gain was examined. The following review examines physiological responses to resistance exercise and goes into depth surrounding the literature on periodisation for maximal strength gain.

2.1 Response to Resistance Exercise

There are a multitude of acute responses to resistance exercise, both muscular and neural in origin, which ultimately may lead to improvements in maximal muscular strength. These responses can be grouped into metabolic fatigue, mechanical tension, exercise induced muscle damage, and neural response. When these stimuli are increased over time through progressively overloaded resistance exercise, muscular and neural systems are stimulated to continually adapt (Peterson, Rhea, & Alvar, 2004).

2.1.1 Metabolic Fatigue

Acute physiological responses to resistance exercise initiate the pathway to chronic adaptation. Typical resistance exercise promotes a manifestation of metabolites including lactate, inorganic phosphate, hydrogen ions, as well as increased hypoxia (Schoenfeld, 2013). High intensity resistance exercise can evoke increases in lactate (and therefore disruptions in pH balance favouring acidosis) due to a breakdown of glycogen during anaerobic metabolism. This lactate response is typically greatest when training intensities are approximately 60-80% of 1RM due to the heavy reliance on anaerobic glycolysis to supply ATP (Schoenfeld, 2013). Alterations in blood lactate and pH balance may contribute to hypertrophy through increasing growth hormone and testosterone concentrations (Nicholson, Mcloughlin, Bissas, & Ispoglou, 2014) however recent evidence challenges this notion (West & Phillips, 2012). Reactive oxygen species production could also play a direct role in hypertrophic adaptation (Takarada et al., 2000). Xanthine oxidase generates reactive oxygen species and is elevated when muscles are subjected to hypoxic conditions, such as that experienced during high intensity exercise or low load with vascular occlusion (Takarada et al., 2000). This has been shown in smooth and cardiac muscle and is hypothesised to occur in skeletal muscle (Schoenfeld, 2010). Such a mechanism may be partly responsible for muscle hypertrophy through occlusion training. Loads as low as 20%, when combined with occlusion, have been successful in stimulating hypertrophy (Loenneke & Pujol, 2009). Inorganic phosphate accumulates following bouts of high intensity activity when adenosine-tri-phosphate is hydrolysed to facilitate muscle contractions and contributes to fatigue (Westerblad, Allen, & Lannergren, 2002), resulting in increased recruitment larger motor units containing fast twitch fibres which have large potential to hypertrophy (Schoenfeld, 2013). Moderate intensity training that is often utilised by bodybuilders, in the 60-80% 1RM range, compared to powerlifters who commonly train above 80%, can result in greater peripherally based metabolic fatigue and enhanced fast twitch fibre recruitment (Schoenfeld, 2013). This may be responsible for the greater hypertrophy in these fibres, particularly IIa fibres, in bodybuilders (Schoenfeld, 2013).

2.1.2 Mechanical Tension

The resulting muscle growth from constant passive tension induced by bone growth during embryogenesis and neonatal development (Powell, Smiley, Mills, & Vandenburgh, 2002) provides simple evidence supporting the role of mechanical tension in muscle growth. In fact, the role of mechanical tension, as occurs when a load is lifted during resistance exercise, is probably the primary factor driving hypertrophy (Schoenfeld, 2013). Powell et al. (2002) found mechanical stimulation of myofibres of human bioartificial muscles caused 12% increases in diameter after eight days; an increase comparable to the study by McCall, Byrnes, Dickinson, Pattany, and Fleck (1996) who carried out a 12 week resistance training protocol in trained participants. More recently, Hornberger (2011) conducted a review in regards to the effect of mechanical tension on a protein kinase, mammalian target of rapamycin (mTOR), namely mTOR1, which is believed to play a central role in muscular adaptation. The review found that the mTOR1 pathway can be activated through phosphatidylinositol 3-kinase/protein kinase B (AKT) stimulation by mechanical signals, growth factors for example insulin, and nutrients such as amino acids and glucose through different pathways. AKT and mTOR phosphorylation is associated with hypertrophy (Baar & Esser, 1999; Léger et al., 2006).

Satellite cells within muscle dwell between the basal lamina and sarcolemma of myofibres (Toth et al., 2011). They can be stimulated through mechanical tension causing hepatocyte growth factor release and binding to a receptor on the cell (Toigo & Boutellier, 2006). They proliferate once stimulated and can combine together or fuse with myofibres and contribute to muscle hypertrophy (Schoenfeld, 2010). This is possible through their ability to donate their nucleus to myofibres and express myogenic regulatory factors responsible for muscle growth and repair (Schoenfeld, 2010).

2.1.3 Exercise Induced Muscle Damage

Exercise-induced muscle damage (EIMD) is the damage to the sarcolemma, connective tissue, basal lamina, contractile elements, cytoskeleton, or macromolecules of muscle tissue (Schoenfeld, 2012). It occurs less when the exercise stimulus is similar to one that has been experienced before (a phenomenon known as the repeated bout effect) and is more obvious following eccentric exercise rather than concentric or isometric (Schoenfeld, 2012). The influence of muscle action, namely that of eccentric nature, on muscle damage may be through mechanical disruption of actomyosin bonds

(Enoka, 1996). An increase in inflammation and protein turnover following EIMD was hypothesised to be necessary for chronic hypertrophy (Evans & Cannon, 1991).

Brentano and Martins (2011) oppose the notion of importance of EIMD stating that it may not be a useful indicator of chronic hypertrophy as low mechanical overloads over a long period of time can result in hypertrophy. Although not of resistance exercise nature, Flann, LaStayo, McClain, Hazel, and Lindstedt (2011) had participants separated into pre-trained (eased into the programme avoiding muscle damage) and naïve groups of an eight-week eccentric cycle ergometry program. Both groups gained equal CSA even though the naïve group experienced greater muscle damage as measured by five times the concentration of creatine kinase and higher perceived soreness and exertion. Thus hypertrophy can still occur without significant muscle damage, and so the associated muscle soreness should not be used as a sole indicator of a successful training session. Perhaps the elevated levels of EIMD in bodybuilders contributes to the increased hypertrophy in general compared with powerlifters, however significant EIMD is probably unnecessary in stimulating long term hypertrophy.

2.1.4 Neural Responses

Resistance training leads to fatigue which can be peripheral or central in origin (Linnamo, Hakkinen, & Komi, 1997). Peripheral fatigue is failure of processes distal to the neuromuscular junction, whereas central fatigue is a decreased ability for the central nervous system (CNS) to recruit motor units and the frequency at which these motor units are recruited (Gandevia, 2001). The magnitude of the neural response to the particular stimulus may be dependent on the amount of central fatigue caused by the training stimulus. The type of fatigue, generated during resistance exercise is dependent on protocol variables such as repetition speed, rest period, contraction type, and intensity (McCaulley et al., 2009). Peripheral fatigue will be heavily determined by the metabolic response to resistance exercise, as discussed in the previous section. Thus, resistance exercise which targets increased muscular hypertrophy (usually involving higher repetitions, volume, and lower intensity than typical strength-focused training) is likely to cause more peripheral fatigue whereas training which targets muscular strength could result in more central fatigue. However, research in this area is sparse.

Surface electromyography (EMG) is used to measure the summation of action potentials during a bout of skeletal muscle contractions (Watanabe, Kouzaki, & Moritani, 2015). Integrated surface EMG increases linearly with force production (Bigland & Lippold, 1954) and thus increase following a training programme designed at increasing strength (Hakkinen & Hakkinen, 1994). Neural drive magnitude can be quantified through the observance of the amount action potentials per time unit (Farina, Holobar, Merletti, & Enoka, 2010). Maximum EMG values have been shown to decrease following fatiguing resistance exercise protocols (Benson, Docherty, & Brandenburg, 2006) indicating central fatigue. However studies such as Bigland-Ritchie, Furbush, and Woods (1986) revealed no change in EMG activity despite decreases in force production. Furthe r research is required to better understand the acute effects of differing training volumes and intensities on the CNS.

2.1.5 Adaptation

Neural adaptations (particularly when an individual is exposed to a new training programme) as well as hypertrophic adaptation contribute to strength improvements (Baker et al., 1994). Novices strength trainers often exhibit rapid neural adaptations including extra doublets (stimulus pulses through motor units), increases in maximal discharge rates of single motor units (Kamen, Knight, Laroche, & Asermely, 1998) and increased motor unit recruitment (Aagaard, 2003). The increase in motor unit firing rate results in increased rate of maximal force development (Aagaard, 2003).

Improved synchronisation of collective motor units (Sale, 1988), addition of new myonuclei, and decrease in antagonist muscle co-activation are other neural adaptations which can improve performance (Hakkinen, Alen, Kallinen, Newton, & Kraemer, 2000). These changes present themselves as increases in EMG magnitude (Sale, 1988). These early neural adaptations are likely the cause of increased strength over the first six weeks of training, and are often accompanied by little or no hypertrophy (Jones & Rutherford, 1987). The rate of adaptive neuromuscular responses decreases considerably as training status increases (Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988).

There is a lack of data linking acute neural responses to chronic neuromuscular adaptation (Bawa, 2002; McCaulley et al., 2009). However, muscular hypertrophy can facilitate gains in maximal strength after initial neural adaptations have taken place (Peterson et al., 2004). Even though a single training session involving heavy resistance exercise can increase protein synthesis, significant increases in the cross sectional area (CSA) of muscle fibres often take approximately two months to occur (Staron et al., 1994). Jones and Rutherford (1987) state that hypertrophy in type II muscle fibres will increase the force per unit area of muscle. This is a major determinant of skeletal muscle strength (Jones & Rutherford, 1987), as a greater CSA of muscle can facilitate future strength improvements (Zourdos, 2012). Baker et al. (1994) reported a significant relationship between positive changes in lean body mass, squat and bench press strength. Therefore, it was suggested that increasing lean body mass (effectively through higher volume protocols and dietary strategies) should be a primary goal when the aim is to improve maximal strength in trained individuals. As such, prolonged periods of low volume, high intensity training is not recommended as hypertrophic adaptations may be impeded, resulting in decreased strength gains (Baker et al., 1994).

Compound movements which involve movements at more than one joint, for example the barbell back squat, may require a longer initial neural adaptation than single joint exercises (Chilibeck, Calder, Sale, & Webber, 1998). Learning and co-ordination become increasingly important in performance gains for movements which are more complex (Rutherford & Jones, 1986). As such, hypertrophy becomes a more important contributor to performance gains later in the training programme when there is less potential for improvements in co-ordination and movement skill. The results of short term training studies (less than 8 weeks) comparing different programming methods are most likely due to rapid neural adaptation, especially when lean body mass gains are the same between groups.

2.2 Training Programmes

In order to identify the effectiveness of various periodisation models, a systematic review was undertaken. Appropriate publications were located by searching the Google Scholar database. Key words used were: muscular strength, maximal strength, one rep max, periodisation, non-periodised, linear periodisation, undulating periodisation, autoregulated, individualised, squat, bench press, trained, and various combinations of these words. Effect sizes (ES) were calculated (where possible) to determine magnitude of strength gains and to ascertain the effectiveness of different periodisation models. Using the equation provided by Flanagan (2013):

$$d = \frac{(MA - MB)}{SD}$$

Where *d*= standardized effect size, MA is the mean of group A, MB is the mean of group B, and SD is the mean standard deviation.

The scale provided by the analysis of Rhea (2004) was utilised when describing strength changes and is illustrated below.

Table 2.1 *Determining the magnitude of effect size in strength training research* (adapted from Rhea, 2004).

Magnitude	Untrained*	Recreationally trained	Highly trained
Trivial	<0.50	<0.35	<0.25
Small	0.50-1.25	0.35-0.80	0.25-0.50
Moderate	1.25-1.9	0.80-1.50	0.50-1.0
Large	>2.0	>1.5	>1.0

*Untrained = individuals who have not been consistently trained for 1 year; Recreationally trained = individuals training consistently from 1-5 years; Highly trained = individuals training for at least 5 years.

2.2.1 Non-periodised Programmes

Early periodisation studies from Berger (1962) (12 weeks) and O'Shea (1966) (6 weeks) reported that in inexperienced weight trained individuals non-periodised programme (NP) strategies were effective at improving maximal bench press and squat strength respectively. Both of these studies compared different programmes using different repetition ranges kept constant throughout the training cycle. O'Shea (1966) had three groups of participants (mixed sex) who completed exercises in different repetition ranges: 9-10, 5-6, and 2-3, whilst Berger (1962) had nine groups of males who differed in set and repetition programming: sets of 1, 2, or 3, and reps of 2, 6, or 10. Weight was increased weekly (O'Shea, 1966) or whenever the repetitions performed exceeded that of the prescribed range (Berger, 1962). This simple form of linear progression may be efficacious for untrained individuals; however it is likely that some form of periodisation would be more effective, especially for trained individuals (Ratamess et al., 2009). For an illustration of intensity and volume within a NP programme, refer to figure 2.1.

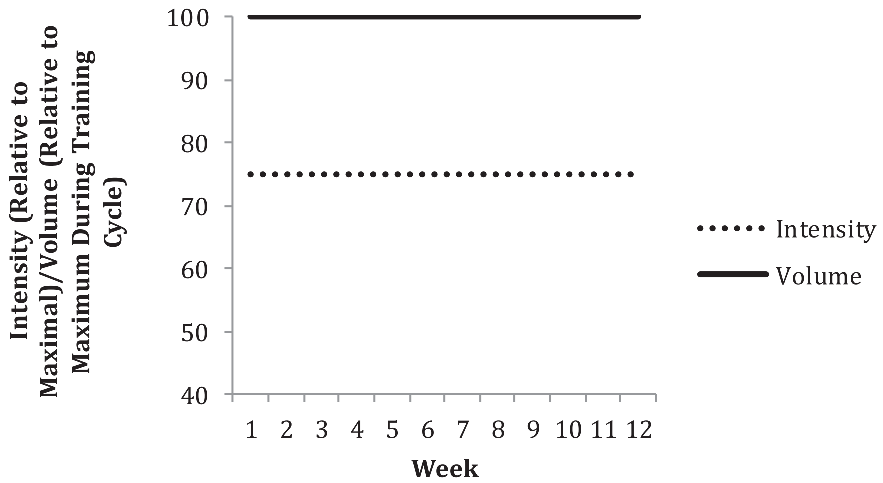

Figure 2.1. Intensity and volume versus time for a NP programme.

2.2.2 Linear Periodisation versus Non-periodised Programmes

NP methods have been compared with LP methods (refer to figure 2.2 for an example illustration of intensity and volume changes over time in a LP programme). For example, Stowers et al. (1983) randomised 84 untrained males into groups of “1 set to exhaustion”, “3 sets to exhaustion” or “periodised” (LP) training groups to investigate squat and bench press 1RM over seven weeks. The LP group had a significantly larger squat 1RM at the cessation of the study. The differences in bench press strength were insignificant. However it is vital to note that the authors compared data sets of each programme at a particular time point rather than comparing the strength gains elicited from each programme. O'Bryant, Byrd, and Stone (1988) also found that LP elicited greater 1RM squat gains compared to NP but it is unclear as to the training status of the participants. In further support of periodised training, Willoughby (1992) recruited trained males (defined as having the capability to lift 150% and 120% of their body weight in the back squat and bench press, respectively) to participate in a study that compared three different training protocols: three sets of ten (3x10) with the same load through the training cycle, 3x6-8 with linear progression applied, and a traditional LP programme. The results showed that 1RM performance improvement was significantly greater in the LP group compared to the other two groups. Large ES of 4.29 and 3.22 were obtained for the LP group 1RM squat and bench press. The NP groups only reached 0.85 and 1.40 for the squat, and 0.79 and 2.26 for the bench press. In an additional study, Willoughby (1993) compared NP to LP on maximal squat and bench press strength in young males fulfilling the same strength criteria as the earlier study. This study was 16 weeks long and had two groups of NP: 5x10 and 6x8, and one LP group. The volume was equal up to 8 weeks, where there was no significant difference in strength gains between protocols. However, beyond week 8, volume significantly decreased in the LP group and intensity increased. This facilitated significantly greater 1RM strength gains in both exercises after 16 weeks. Total volume over the training programme was lower in the LP group however the amount of volume spent at a higher intensity was greater, which was likely responsible for the enhanced strength gains.

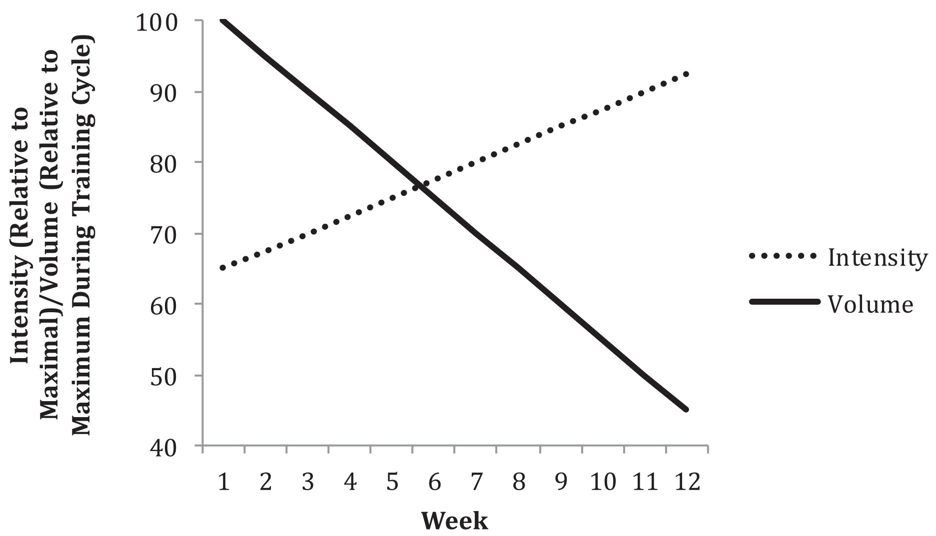

Figure 2.2. Intensity and volume versus time for a LP programme.

2.2.3 Reverse Linear Periodisation

Reverse linear periodisation (RLP) is simply the opposite of LP. In the beginning of the training cycle, training volume is low and intensity is high, and progresses to higher volume and lower intensity (figure 2.3). There has been scant research conducted on this type of training. However, Prestes et al. (2009a) compared RLP and LP with the aim of enhancing strength and hypertrophy during 12 weeks in strength trained females. Volume and intensity were equated between groups. Strength in the bench press, leg extension, arm curl, and lat pulldown all increased with both programmes, however only the improvements of the latter two movements were significantly greater in the LP group.

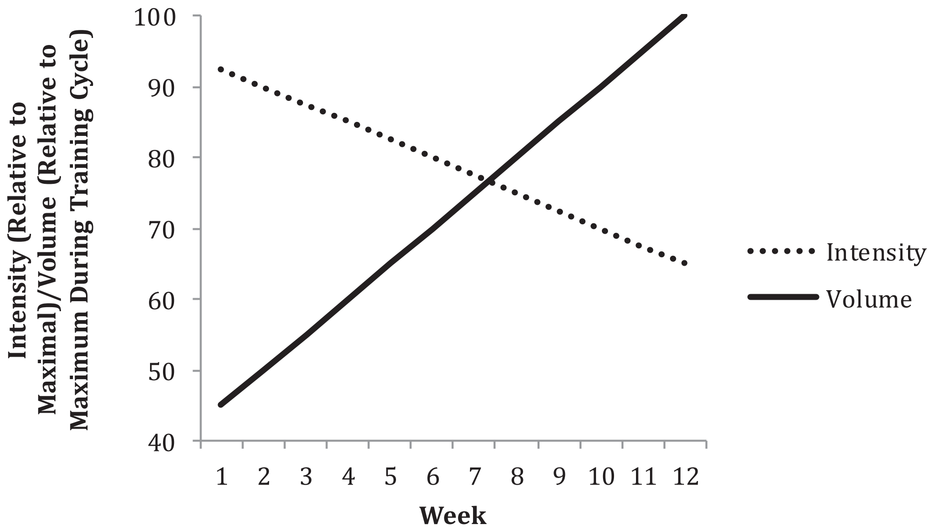

Figure 2.3. Intensity and volume versus time for a RLP programme.

2.2.4 Undulating Periodisation

Poliquin (1988) proposed two major problems with traditional LP. Firstly, the ever-increasing intensity creates high levels of stress and little time for regeneration that may promote overtraining. Secondly, some hypertrophy gained in the early stages of the programme may be lost in the intensification phase due to the decrease in volume. He suggested that UP is superior within which average volume decreases slowly over the course of the training cycle, and intensity builds up in a gradual fashion (figure 2.4). Short periods of high volume training are alternated with high intensity training, potentially within the same week (Apel, Lacey, & Kell, 2011). This frequent change in training stimulus could allow better strength gains (Poliquin, 1988) through fluctuations in motor unit recruitment thus causing greater neural adaptation (Monteiro et al., 2009). The greater training load variability with UP may also result in less desensitisation to stimuli, facilitating greater adaptation (Rhea et al., 2002). Currently, most of the literature fails to find a significant difference between LP and UP models on strength gains, at least in participants with limited resistance training experience (Harries et al., 2015b). There is a lack of studies examining the effectiveness of UP versus LP in highly resistance trained populations (Harries et al., 2015b). However, the studies done by Monteiro et al. (2009) and Rhea et al. (2002) found UP superior, with the results of Miranda et al. (2011) and Prestes et al. (2009b) appearing to favour UP but lacking significance.

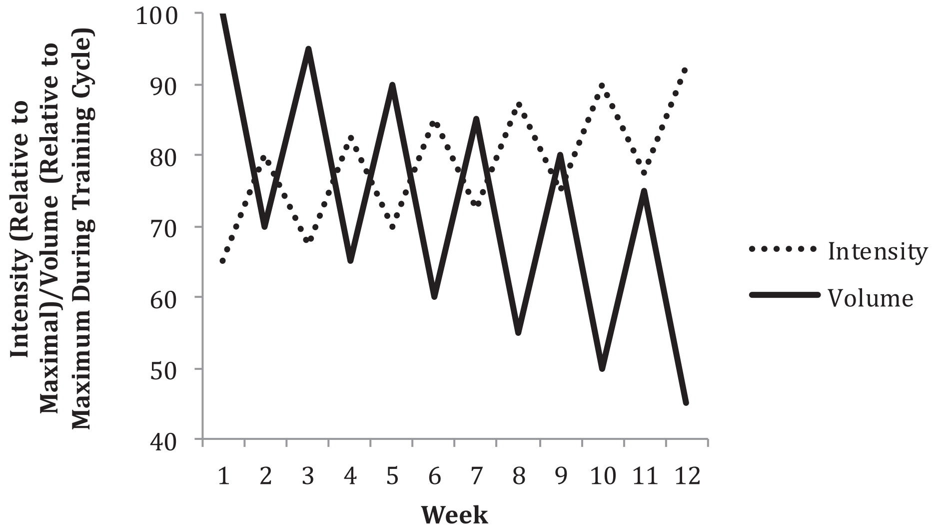

Figure 2.4 Intensity and volume versus time for a WUP Programme.

Baker et al. (1994) compared 12-week LP, UP, and NP training programmes on 1RM squat and bench press performance in novice weight trained males. The LP group performed 5x10 for the squat and bench press for the first four weeks, followed by 5x5 for four weeks, 3x3 and 1x10 for three weeks, and then 3x3 in the final week. The UP group changed protocol every two weeks: 5x10, 5x6, 5x8, 5x4, 5x6, and 4x3, in comparison to the control group that performed 5x6 through weeks one to twelve. Participants progressively increased all training loads throughout the study. Total repetitions performed and relative intensity (repetition maximum) was equated between groups for both core and assistance exercises. Performance gains were not significantly different between groups. This suggests that when volume and intensity are equated between groups during a short training programme, and with participants of this experience, adaptations evoked are not different. However, the use of inexperienced individuals in short term weight training studies comparing programming methods can be inappropriate. This is due to the rapid initial neural adaptation from the stimulus of a new exercise, which is promoted by most training styles. Therefore, in short term studies it may be difficult to establish significant differences between programmes as they may all result in similar neural gains (Fleck, 1999).

2.2.4.1 Daily and Weekly Undulating Periodisation

DUP and WUP are methods of training that within which, intensity and volume can be altered on a frequent basis, compared to than other periodisation styles. With DUP, there are variations in intensity and volume within a training week for a similar movement; these variations are weekly with WUP. Monteiro et al. (2009) conducted a three month long training study on 27 healthy-trained males which compared the effectiveness of NP, LP, and DUP. It is important to note that these participants were far more trained than those in other studies; having trained at least four times per week for at least two years prior to the study with regular engagement in squat and bench press exercises. They were also strength matched at the beginning of the study. The NP group performed 3x8-10RM every training session. The LP group performed 3x12-15RM the first week, 3x8-10RM the second, 3x4-5RM the third, and 3x12-8-4RM during a recovery fourth week. This four week cycle was completed three times over the course of the study. As such, it is not representative of a typical LP programme (but instead similar to WUP) due to the more rapid shifts in volume and intensity week to week. The DUP group utilised the same repetition ranges as the LP group however they were alternated each training session. Volume was matched between groups. The DUP group was more effective than the NP and LP group at improving maximal strength as hypothesised, however there were no differences between the NP and LP group. The latter result was not expected based on the assumption that a greater variability of training load would facilitate less desensitisation and therefore more adaptation as proposed by Rhea et al. (2002). Although participants were trained, neural adaptation played an important role in strength change, as illustrated by a lack of change in anthropometric profile (Monteiro et al., 2009). Rhea et al. (2002) compared a more typical LP programme with DUP in trained males, with a volume and intensity matched design (refer to Table 2.2), similar to that of Monteiro et al. (2009). DUP was superior at producing maximal strength gains in the leg press and bench press. However, participants were not strength matched in the leg press prior to commencement of the study, perhaps confounding the greater increase in strength attributed to the DUP scheme.

Perhaps more importantly, studies involving periodisation for maximal strength gains in trained athletes have also been undertaken. Hoffman et al. (2009) compared NP, LP, and DUP over a 15 week off-season programme in 51 American football players of an NCAA Division III football team. The performance measure included 1RM bench press and squat. Total volume and average intensity appear to have been controlled, with manipulations of volume and intensity at different stages for the LP and DUP group. All groups improved in strength, with no statistical difference being reported. Similarly, Harries, Lubans, and Callister (2015a) compared a 12 week DUP programme versus LP programme for development of 5RM strength in the box squat and bench press in 26 adolescent rugby union players. This study also had a control group who performed no resistance exercise. Those in the DUP and LP groups had 6 months of resistance exercise experience prior to commencement of the study. Like the results of Hoffman et al. (2009) there were no clear differences between the adaptations promoted by each programme, perhaps due to the training status of the participants.

Consistent with Harries et al. (2015a) and Hoffman et al. (2009), Miranda et al. (2011) found DUP and LP prescribed over 12 weeks to trained individuals to cause significant increases in leg press and bench press 1RM and 8RM strength however no differences were apparent between groups. The authors proposed that this may have been due to the DUP group having higher baseline strength. ES were larger in the DUP group, partially supporting the notion that DUP is a superior form of periodisation for trained individuals. Peterson, Dodd, Alvar, Rhea, and Favre (2008) found insignificant differences between DUP and BP in trained males on maximal strength gains over a 3 month period, with controlled volume and intensity. Prestes et al. (2009b) also revealed insignificant differences in bench press and leg press strength following a 12 week DUP programme compared to LP in strength trained individuals. Unlike other studies, Buford, Rossi, Smith, and Warren (2007) compared both DUP and WUP with LP on bench press and leg press strength in males and females with limited weight training experience, over 9 weeks. No significant differences were found between groups. However, the DUP group did produce lower percentage changes in strength, indicating that either or both of the following theories may be applicable: the participants were not trained enough to benefit from the positive effects of a UP, or no performed improvement difference based on the periodisation model is seen in early-phase training (Buford et al., 2007). It is important to note that the LP and WUP groups reported lower ratings of perceived exertion (RPE) at the end of the programme compared to the beginning, compared to the DUP group that reported increased RPE. This could be an important consideration for training recreationally active individuals, as a higher RPE early in a programme may result in reduced exercise adherence to a programme and discontinuation (Buford et al., 2007).

Another study utilising WUP was conducted by Apel et al. (2011) with the use of 10RM as the performance measure rather than maximal testing. Forty two healthy recreationally trained men were recruited for the study comparing 12 weeks of WUP to a “traditional periodised programme” which resembled LP. The programmes were identical other than the WUP group exhibited greater variance of training intensity between the weeks. Ten RM testing was conducted every fourth week. This provided the TD group an element of WUP due to higher repetition, lower percentage training near the end of the training cycle. At week 8, gains were similar between groups but at week 12 the TD group outperformed the WUP group. Squat, bench press, and lat pulldown performance improvements were significantly greater in the TD group at week 12 with notable ES differences (Table 2.2). The authors proposed that this was due to the WUD experiencing more delayed-onset muscle soreness and fatigue than the TD; these factors may have negatively impacted the group’s ability to perform 10RM testing in week 12.

2.2.5 Block Periodisation

BP is made up of several mesocycles, each with a unique training goal that prepares the athlete for the subsequent training block (Bartolomei et al., 2014). It involves an accumulation block of high volume, relatively low intensity training, followed by transformation and realisation blocks (Bartolomei et al., 2014) (figure 2.5). These blocks have the goal of developing muscular hypertrophy, maximal strength, and power, respectively (Bartolomei et al., 2014). Bartolomei et al. (2014) had 24 trained men undergo a 15 week TD or BP with the goal to increase upper and lower body strength and power. Each group completed three mesocycles, within which the TD group compacted “hypertrophy, maximal strength, and power” style training into each five week section, whereas the BP group had one entire mesocycle dedicated to each of those fitness elements. As such, the TD group resembled WUP. At the end of the 15 weeks, the BP group had shown greater improvements in strength and power expression in the bench press but no differences existed between squat strength or power, or power assessments of standing jump or countermovement jump.

Painter et al. (2012) also compared a form of UP, DUP, with BP on performance measures including 1RM squat. This was performed by 14 (mixed sex) track athletes. The BP programme was arranged in a similar fashion to that by Bartolomei et al. (2014) with higher repetitions and lower intensity early in the programme, transitioning into lower repetitions and higher intensity. This arrangement looked very similar to that of a typical LP programme. In the DUP group the repetition ranges were similar however the focus on strength/endurance, strength, and power, were alternated on days during the week. There were no significant differences between performance measures of the groups. However, the BP method was more efficient at the performance gains that it caused shown by less total repetitions and volume load.

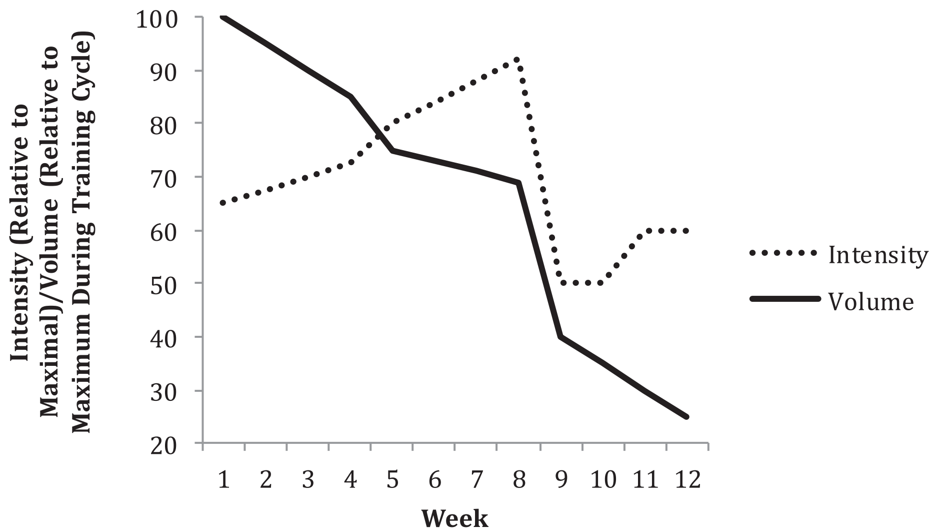

Figure 2.5. Intensity and volume versus time for a BP programme representing blocks of muscular hypertrophy, maximal strength, and power.

2.2.6 Autoregulated Periodisation

Traditional periodised strength plans manipulate intensity as a percentage of 1RM; this maximal value is obtained prior to the beginning of the training phase. However, there are day to day fluctuations in strength, due to fatigue and improving strength levels which may affect the accuracy of prescribing training based from a one-off maximal value. Within a single day, strength can vary 10-20%, resulting in a variable amount of repetitions when using a fixed percentage of 1RM (Poliquin, 1988). Some training days may not provide enough stimuli for optimal adaptation, while others may provide too much stimulus resulting in fatigue that is not desirable for a particular stage of the training phase. The potential for strength gain in some individuals may be greater than a traditional programme can facilitate, as such a method of incorporating some form of AR may allow rapid gains. These reasons justify AR as a tool within programming as it allows an individual to increase strength at their own pace (Siff, 2003). Also, AR programmes often result in a constant adjustment of repetitions which may prevent training plateaus (Mann, Thyfault, Ivey, & Sayers, 2010).

Known as the daily adjustable progressive resistive exercise (DAPRE), this form of AR has previously been used for rehabilitating athletes (Knight, 1979). For example, in a training session where approximately a 6RM will be used: 50% of 6RM x 10, followed by 75% of 6RM x 6, then 100% of 6RM load for a set to fatigue is prescribed. A fourth set based on how many repetitions were achieved in the third set is performed. The number of repetitions completed in the fourth set is used to determine the working weight for the next week. This can facilitate rapid strength gains without the possibility of excessive resistance overloading the joints and tissues (Wilson, 2008). Ardali (2014) & Horschig et al. (2014) have both utilised adjustable progressive resistive exercise in rehabilitation of patients recovering from knee replacement surgery and anterior cruciate ligament reconstruction, respectively. Both reported improved rehabilitation (Ardali, 2014).

However, there is a lack of research in the area of AR strength training programmes, particularly for healthy athletes. Mann et al. (2010) compared a form of AR training to LP training on strength improvement in National Collegiate Athletic Association division I American football players. They used three protocols involving loads corresponding to 10RM, 6RM, and 3RM with a structure based on Delorme's RPE programme (Siff, 2003). Four sets were performed per exercise with the load increased up for two sets, in the same style as that previously explained in the study by Knight (1979). Thus, this form of AR was not solely daily but also dictated weekly changes in load. This study consisted of four weeks of training for the squat and five for the bench press not inclusive of testing weeks. Volume and intensity were not attempted to be controlled as it would have been exceedingly difficult to do so with the inclusion of as many repetitions as possible (AMRAP) sets. However, this may not be unfavourable as differences in volume and intensity may be a reason why AR programming is effective. Notably, the study design may have actually been DUP rather than LP as the authors mentioned that in addition to the programme, each group performed heavy barbell bench press >85% of 1RM and multiple repetition 225lb bench press performed once per week. Squat, maximal bench press, and the 225lb bench press test all improved significantly greater in the AR group. However, the LP group was significantly more trained at baseline in the 1RM bench press and repetition test than the AR group. The study was short duration (4-5 weeks) and a stronger methodology could have included a crossover design with strength matched participants. McNamara and Stearne (2010) also examined a form of AR training on maximal strength gain, in inexperienced weight trainers. A 12 week programme of UP was compared with AR whereby participants could choose from a selection of workouts; training intensities of either their 10RM, 15RM, or 20RM. Volume and intensity was equated between groups. To ensure volume and intensity were matched, the AR group had limited selection of workouts at the end of the study. Leg press strength improvements were significantly greater in the AR group, but chest press strength improvements were similar.

The Reactive Training Manual (2008) developed by Michael Tuchscherer describes a method of AR style training that is utilised by many powerlifters around the world. A rating of perceived exertion

(RPE) scale is used whereby the trainee rates their performance of each set based on how many repetitions they perceive they could have additionally completed, before muscular failure. Effectively, it is a measure of repetitions in reserve (RIR) and may be more applicable to resistance training than methods of RPE commonly undertaken during endurance training (Zourdos et al., 2015). For example a RPE of 8 or 9 indicates two or one extra repetitions, respectively, could have been completed before failure. This guides the training session as to what load should be used. Hackett, Johnson, Halaki, and Chow (2012) assessed the efficacy of a RIR scale to predict actual repetitions to failure during 5x10 at 70% 1RM squat and bench press in highly experienced strength trained participants (1RM bench press 148 ± 11 kg and squat 208 ± 22 kg). Participants were asked to give a RIR rating following 10 repetitions, and then continued to volitional fatigue. The RIR values reported by participants were not significantly different to the repetitions completed at the end of the set for any set; however the accuracy of the RIR scale was enhanced in sets 3, 4, and 5. Thus, the method described by Tuchscherer (2008) may be effective for predicting an individual's performance on the day, at least for the highly trained population.

AR combined with LP or UP programmes may facilitate greater strength improvements over the long term. Most of the training methods mentioned, utilise percentages of one repetition maximum (1RM), obtained prior to the beginning of the training cycle to dictate load for the entirety of the training cycle. While this is successful in facilitating strength gain, it may be suboptimal due for several reasons. Firstly, the 1RM obtained may be limited due to atypical performance on testing day or inappropriate testing procedures, leading to suboptimal load prescription (Zourdos et al., 2015). Secondly, rates of individual progression can vary through recovery (Fisher, Steele, Bruce-Low, & Smith, 2011) and adaptation (Timmons, 2011) differences. These are often not catered for by traditional non-AR programmes, and could facilitate overtraining, or sub-optimal progression (Poliquin, 1988).

AR programmes have the potential to offer greater motivation and enjoyment than traditional programmes due to the opportunity of surpassing one's previous performance on multiple occasions if progression is rapid. Contrary, AR programmes can leave a motivated individual disappointed if they are unable to consecutively improve their performance between sessions. Regulating intensity through RIR based on objective performance can be accurate for highly trained individuals (Hackett et al., 2012); however for less experienced individuals AR with the assistance of a RIR scale may be less applicable. Individuals may also acquire a learned behaviour whereby they could associate lack of motivation with an easier workout and thus use this as an excuse (McNamara & Stearne, 2010).

The prescription of RM to dictate training intensity rather than a percentage of 1RM is a method that is often used to prescribe week to week progression. For example, the subsequent week's training load could be increased when RM exceeded that of the target repetition zone for a given training session; this is a type of AR. This type of training can be useful for adjusting week to week fluctuations in performance and remaining in the desired intensity range (Tan, 1999) and has been previously utilised by Berger (1962).

2.2.7 Limitations of Previous Research

The lack of a clear, preferred periodisation model may be due to several important limitations. Studies comparing periodisation models are often confounded by unmatched total volume and/or intensity. Differences in such variables may result in differences in results between different training methodologies (Cissik, Hedrick, & Barnes, 2008). Willoughby (1993) reported that LP was superior to NP however intensity was not controlled and the LP group had sections of training where intensity was far greater in the LP group (3-4RM versus 6-8RM the weeks prior to final testing). This creates difficulty in establishing whether the periodisation model used was responsible for differences in progression; or simply due to the differences in volume and/or intensity. However, some studies have found different arrangement of volume and intensity (DUP vs. LP) to promote different adaptation although volume and intensity are matched in total (Rhea et al., 2002). It is also difficult to identify the particular periodised design in some research. For example, the study by Monteiro et al. (2009) claimed to compare NP, LP, and DUP over 12 weeks. However, the LP group clearly resembled WUP as repetition ranges were alternated each week and then reset to higher repetitions every 5th week. Care has to be taken when attempting to draw conclusions about which periodisation model is more effective when there is difficulty in identifying the type of model employed.

Certainly, the advantages of some periodised models are their facilitation of more desirable volume and/intensity for a stage of the training cycle that could allow greater progression; an example of this would be the LP versus NP model of Rhea and Alderman (2004). AR programmes may be superior to LP because of this: facilitating higher loads and volumes in times where the individual is primed, and allow both of these variables to be eased when the individual has large residual fatigue. Consideration needs to be made before controlling volume and/or intensity to ensure that the distinct advantage of a certain programme is not undermined. It is important to note that strength training research is seldom conducted for longer than 3 months at a time.

2.2.8 Summary

In summary, it appears as though the literature favours LP over NP in strength improvements (O'Bryant et al., 1988; Willoughby, 1992, 1993). However, when identifying the most effective periodisation model, using effect sizes (Table 2.2), no single model stands out as being the best. Some studies (Monteiro et al., 2009; Rhea et al., 2002) found DUP superior to LP in trained individuals, however others (Apel et al., 2011) found the opposite. Practically, UP may be more effective than LP for in-season strength and power athletes requiring maintenance of both muscle size and strength due to the fluctuations in volume and intensity. AR training is a tool to implement within a periodised programme and may be more favourable than a training regime that strictly prescribes percentage guidelines. Recently, it has been implemented on athletes and positive results were reported (Mann et al., 2010), but, more research is required to determine its efficacy.

Table 2.2. *Summary of the methodology and performance changes of the various periodisation methods.*

Study	Population	Training history	Performance measures	Periodisation methods	Duration	Change in performance from baseline to final testing stage (% change, effect size). Between-programme improvements significance level. ▲▲ = statistically significant ▲ = non-statistically significant.
Apel et al. (2011)	42 males	Recreationally weight trained	Squat 10RM, bench press 10RM, lat pulldown 10RM, leg extension 10RM, dumbbell shoulder press 10RM.	Both groups had an initial 3 week moderate volume & intensity phase. **<u>Traditional (TD):</u>** Intensity rising from week 5 onwards. **<u>WUP</u>**: Matched intensities but fluctuating weekly.	12 weeks	Squat 10RM: ▲▲ TD – (53.5%, 2.78) WUP – (33.7%, 1.55) Bench press 10RM: ▲▲ TD – (23.9%, 1.45) WUP – (18.6%, 0.99) Lat pulldown 10RM: ▲▲ TD – (28.8%, 1.89) WUP – (19.4%, 1.18) ▲Leg extension 10RM: TD – (39.3%, 1.43) WUP – (27.1%, 1.13) ▲ Dumbbell shoulder press 10RM: TD – (47.6%, 1.60) WUP – (36.4%, 1.24)
Baker et al. (1994)	22 males	Recreationally weight trained	Squat 1RM, bench Press 1RM,	**<u>NP:</u>** 5x6 for weeks 1-12 (constant volume and relative intensity). **<u>LP:</u>** 5x10 for 4 weeks, 5x5 for 4 weeks, 3x3 and 1x10 for 3 weeks, and 3x3 in the final week. **<u>UP:</u>** 5x10, 5x6, 5x8, 5x4, 5x6, 4x3 (alternated every 2 weeks). Weight progressively increased through the study.	12 weeks	▲ Squat 1RM: NP – (24.9%, 1.40) LP – (25.3%, 1.00) UP – (25.2%, 1.02) ▲ Bench press 1RM: NP – (12.2%, 0.86) LP – (11.4%, 0.75) UP – (16.0%, 1.13)

tudy	Population	Training history	Performance measures	Periodisation methods	Duration	Change in performance from baseline to final testing stage (% change, effect size). Between-programme improvements significance level. ▲▲ = statistically significant ▲ = non-statistically significant.
Bartolomei et al. (2014)	24 Males	3+ years' experience at training 3+ times per week	Maximal isometric strength in half-squat position, bench press 1RM	**TD (WUP style):** "Hypertrophy, maximal strength, and power" combined into a 5-week section which focused on higher volume, lower intensity at the beginning. This cycle was repeated 3 times. **BP:** "Hypertrophy, maximal strength, and power" each occupying its own five week section	15 weeks	▲ Isometric Squat TD – (7.1%, 0.20) BP – (4.8%, 0.20) ▲ Bench press 1RM TD – (2.0%, 0.08) BP – (7.6%, 0.26)
Berger. (1962)	177 males	Inexperienced, weightlifting students	Bench press 1RM	**NP:** 9 Groups, sets of 1, 2, or 3 at repetitions of 2, 6, or 10. Weight increased for the next session when repetitions performed exceeded the target zone.	12 weeks	3x6 most successful compared to baseline (30.2%, 1.73)
Buford et al. (2007)	30 mixed sex	Inexperienced	Bench press 1RM, Leg Press 1RM	**LP:** 3x8 for weeks 1-3, 3x6 for weeks 4-6, 3x4 for weeks 7-9. **DUP:** Same set & rep scheme but alternated every training session. **WUP:** Same set & rep scheme but alternated every week.	9 weeks	▲ Bench press 1RM: LP – (24.2%, 0.57) DUP – (17.5%, 0.37) WUP - (24.5%, 0.84) ▲ Leg Press 1RM: LP – (85.3%, 2.24) DUP – (79.0%, 2.10) WUP – (99.7%, 2.93)
Harries et al. (2015a)	26 adolescent males	Rugby union players (6 months of resistance exercise experience)	Box squat 5RM Bench press 5RM	Two 6 week training blocks **LP:** sets of 10, 8, 6, 5, 4, and 3 (change each week) **DUP:** First and 2nd week sets of 10 and 5, 3rd and 4th week sets of 8 and 4, 5th and 6th week sets of 6 and 3.	12 weeks	▲ Box Squat 1RM estimate: LP: (33.9%, 1.28) DUP: (44.5%, 1.81) ▲ Bench press 1RM estimate: LP - (10.9%, 0.50) DUP - (7.0%, 0.30)
Hoffman et al. (2009)	51 males	NCAA Division III American football players (resistance trained)	Squat 1RM Bench press 1RM	**NP:** Sets of 6-8 throughout programme. Weight increased when 8 reps were achieved for 2 consecutive sessions. **LP:** 4 weeks of 9-12, 6 weeks of 6-8, 4 weeks of 3-5. **DUP:** Same repetition ranges as LP but alternated each training session.	15 weeks	▲ Squat 1RM: NP - (20.4%, 1.61) LP - (20.7%, 1.46) DUP - (11.1%, 0.75) ▲ Bench press 1RM: NP - (8.7%, 1.00) LP - (7.8%, 0.47) DUP: (8.3%, 0.40)
Study	Population	Training history	Performance	Periodisation methods	Duration	Change in performance from baseline to final testing stage (% change, effect size). Between-programme improvements significance level. ▲▲ = statistically significant ▲ = non-

			measures			statistically significant.
Mann et al. (2010)	23 males	Division I American football players (~2-3 years of resistance training experience)	Estimated squat 1RM (5 or less repetitions to failure) bench press 1RM bench press 225lb test	**LP:** (each week) Squat: 3x8 with 70%, 4x6 with 75%, 4x5 with 80%, 4x5 with 85%, week 5 test. Bench press: 3x8 with 70%, 4x6 at 75%, 4x5 at 80%, 4x5 at 82%, 4x5 at 85%, week 6 test. **AR:** 10RM, 6RM, and a 3RM protocol. For example the 6RM protocol: 1x10 at 50% anticipated 6RM, 1x6 at 75% anticipated 6RM, AMRAP with 100% anticipated 6RM. Set 4 & next training session dependent on repetitions of set 3.	4-5 weeks	Estimated squat 1RM: LP - (1.9%, 0.15) ▲▲ AR - (9.1%, 0.90) Bench press 1RM: LP - (0.0%, 0.00) ▲▲ AR - (7.1%, 0.83) Bench press repetition test: LP - (0.0%, 0.02) ▲▲ AR - (32.0%, 0.90)
McNamara and Stearne (2010)	16 mixed sex	An average of 1.35 years weights training experience	Leg press 1RM, Bench press 1RM	**UP:** Random allocation of 10RM, 15RM, or 20RM loads. **AR:** Participants were able to select training intensities at 10RM, 15RM, or 20RM depending on their mood. Volume and intensity equated between groups.	12 weeks	Leg press 1RM (exact values not reported): ▲▲ UP ▲ Bench press 1RM (exact values not reported):
Miranda et al. (2011)	20 males	2+ years of resistance training experience	Bench press 1RM Leg press 1RM	**LP:** 3x8-10RM for 4 weeks, 3x6-8RM for 4 weeks, 3x4-6RM for 4 weeks. **DUP:** the same repetition protocol but varied each training session.	12 weeks	▲ Bench press 1RM: LP - (15.1%, 0.75) DUP - (16.3%, 0.95) ▲ Leg press 1RM: LP - (5.9%, 0.75) DUP - (18.2%, 1.52)
Monteiro et al. (2009)	27 males	Trained at least 4x/week for at least 2 years prior	Bench press 1RM Leg press 1RM	**NP:** 3x8-10RM every training session **LP:** 3x12-15RM week 1, 3x8-10RM week 2, 3x4-5RM week 3, 3x12-8-4RM recovery week 4. Repeated 3 times. (more representative of a WUP scheme). **DUP:** same repetition ranges but alternated every training session.	12 weeks	Bench press 1RM (exact values not reported): ▲▲ DUP Leg press 1RM (exact values not reported): ▲▲ DUP
O'Bryant et al. (1988)	90 males	Not reported	Squat 1RM	**NP:** 3x6RM over 11 weeks. **LP:** Movement of high volume, low intensity to low volume, high intensity.	11 weeks	Squat 1RM: NP - (29.4%, SD not reported) ▲▲ LP – (38.2%, SD not reported)

Study	Population	Training history	Performance measures	Periodisation methods	Duration	Change in performance from baseline to final testing stage (% change, effect size). Between-programme improvements significance level. ▲▲ = statistically significant ▲ = non-statistically significant.
O'Shea (1966)	30 (unstated sex)	Inexperienced, weightlifting students	Squat 1RM, static strength on back and leg dynamometer.	**NP:** 3 groups; sets of 9-10 (A), 5-6 (B), and 2-3 (C). Weight increased 5lb weekly.	6 weeks	▲ Squat 1RM: A – (20.4%, SD not reported) B – (26.7%, SD not reported) C- (21.8%, SD not reported) ▲ Static Strength: A – (21.1%, SD not reported) B – (15.5%, SD not reported) C- (23.2%, SD not reported)
Painter et al. (2012)	14 mixed sex	Track athletes who reportedly did not train primarily endurance activities prior to the study	Squat 1RM	**DUP:** 3x8-12, 3x5-7, 3x3-5 alternated each training session. **BP:** 4 Weeks of strength/endurance focus, 4 weeks of strength focus, 2 weeks of power focus. Sets and repetitions similar to DUP but fitness focus arranged in week blocks rather than varied daily.	10 weeks	▲ Squat 1RM: DUP – (1.5%, 0.05) BP – (3.9%, 0.12)
Peterson et al. (2008)	14 males	Well trained fire-fighter academy attendees	Squat 1RM Bench Press 1RM	**BP:** endurance/hypertrophy phase, strength phase, power/speed phase. 3 Weeks each **DUP:** the same phases however alternated every training session rather than every 3 weeks.	12 weeks	▲ Squat 1RM: BP – (16.8%, 1.47) DUP – (20.5%, 0.89) ▲ Bench press 1RM: BP – (8.7%, 0.37) DUP – (16.8%, 0.66)

Study	Population	Training history	Performance measures	Periodisation methods	Duration	Change in performance from baseline to final testing stage (% change, effect size). Between-programme improvements significance level. ▲▲ = statistically significant ▲ = non-statistically significant.
Prestes et al. (2009a)	20 females	At least 6 months of weights training experience	Bench Press 1RM, Lat pulldown 1RM, Arm curl 1RM, Leg extension 1RM	**LP:** sets of 4-14 arranged in LP fashion over 3-4 week cycles. **RLP:** the opposite; greater emphasis on 4-6 reps at beginning of training phase.	12 weeks	▲ Bench press 1RM: LP – (17.4%, SD not reported) RLP – (16.6%, SD not reported) Lat pulldown 1RM: ▲▲ LP – (29.5%, SD not reported) RLP – (22.0%, SD not reported) Arm curl 1RM: ▲▲ LP – (20.4%, SD not reported) RLP – (15.7%, SD not reported) ▲ Leg extension 1RM: LP – (36.8%, SD not reported) RLP – (31.8%, SD not reported)
Prestes et al. (2009b)	40 males	Recreationally trained: 1 year+ of weight training experience	Bench press 1RM, Leg press 1RM, Arm curl 1RM	**LP:** 3 sets of 12, 10, 8, 6RM repeated 3 times over 4 week phases. **DUP:** Same set/rep scheme but alternated during the week.	12 weeks	▲ Bench press 1RM: LP – (18.2%, 3.11) DUP – (25.1%, 5.05) ▲ Leg Press 1RM: LP – (24.7%, 3.91) DUP – (40.6%, 10.6) ▲ Arm curl 1RM: LP – (14.2%, 3.11) DUP – (23.5%, 3.51)
Rhea et al. (2002)	20 males	Recreationally trained: weight trained at least 2 days per week for at least 2 years.	Bench press 1RM, Leg press 1RM	**LP:** sets of 8RM weeks 1-4, 6RM weeks 5-8, 4RM weeks 9-12. **DUP:** equated volume and intensity and set/rep scheme but alternated every training day (3x/week)	12 weeks	Bench press 1RM: LP – (13.4%, 0.94) ▲▲ DUP – (25.3%, 0.85) Leg press 1RM: LP – (24.2%, 1.04) ▲▲ DUP – (52.1%, 1.65)

Study	Population	Training history	Performance measures	Periodisation methods	Duration	Change in performance from baseline to final testing stage (% change, effect size). Between-programme improvements significance level. ▲▲ = statistically significant ▲ = non-statistically significant.
Stowers et al. (1983)	84 males	Inexperienced	Squat 1RM, Bench press 1RM	**NP 1:** 1 set to exhaustion (10-12 reps each set). Weight increased at individual pace. **NP 3:** 3 sets to exhaustion (10-12 reps each set). Weight increased at individual pace. **LP:** 2 weeks of 5x10, 3 weeks of 3x5, 2 weeks of 3x3.	7 weeks	▲ Squat 1RM: NP 1 – (14.9%, SD not reported) NP 3 – (19.8%, SD not reported) LP – (27.1%, SD not reported) Note: the LP data set was reported significantly different (greater) to the NP 1 and NP 3 data sets at final testing. Authors did not note whether the *improvements* between protocols was significant. ▲ Bench press 1RM: NP 1 – (7.2%, SD not reported) NP 3 – (9.6%, SD not reported) LP – (8.4%, SD not reported)
Willoughby (1992)	T 48 males	Trained: (capable of squatting and bench pressing 150% and 120% of their body weight, respectively)	Squat 1RM, Bench press 1RM	**NP 1:** 3x10 with weight kept static **NP 2:** 3x6-8 with linear progression applied **Traditional LP programme.**	12 weeks	Squat 1RM: NP 1: (13.2%, 0.85) NP 2: (37.3%, 1.40) ▲▲ LP: (47.2%, 4.29) Bench press 1RM: NP 1: (8.3%, 0.79) NP 2: (17.5%, 2.26) ▲▲ LP: (28.7%, 3.22)
Willoughby (1993)	92 males	Trained: (capable of squatting and bench pressing 150% and 120% of their body weight, respectively)	Squat 1RM, Bench press 1RM	**NP 1:** 5x10-RM at 79% 1RM, constant load **NP 2:** 6x8-RM at 83% 1RM, constant load **LP:** 4 weeks of NP1 protocol, 4 weeks of NP2 protocol, 4 weeks of 3x6-RM at 88% 1RM, 4 weeks of 3x4-RM with 92.4% of 1RM.	16 weeks	Squat 1RM: NP 1: (16.0%, SD not reported) NP 2: (26.0%, SD not reported) ▲▲ LP: (34.7%, SD not reported) Bench press 1RM: NP 1: (7.8%, SD not reported) NP 2: (8.5%, SD not reported) ▲▲ LP: (24.0%, SD not reported)

2.3 Maximal Strength Testing

In sports such as power lifting, maximal strength performance ultimately determines the victor of each weight and age category. In other sports where maximal strength makes a contribution to performance, such as rugby or American football, maximal strength testing is also undertaken. Often, strength testing is used to quantify a baseline strength from which training loads are prescribed, progressed, and monitored. Various tests of maximal strength including absolute 1RM strength or RM tests and subsequent 1RM estimation (based on an equati on) are performed to compare different programming methods.

When testing maximal strength, using submaximal loads, it is important to consider the method that caters to the population and exercise being investigated. Dohoney, Chromiak, Lemire, Abadie, and Kovacs (2002) discovered that a load corresponding to 4-6RM was more accurate in predicting 1RM than a lighter load corresponding to 7-10RM. In Brechque and Mayhew (2012) and Brechue and Mayhew (2009) loads of 80-85% 1RM to fatigue were the most accurate at predicting 1RM for squats and bench press. Interestingly, Shimano et al. (2006) found both trained and untrained participants could complete more repetitions to fatigue at 80% of the squat than the bench press. Thus, different 1RM estimations may be needed for each exercise. Shimano et al. (2006) proposed that this could be related to asynchronous motor unit firing. With squats, more total motor units can be utilised to move the weight which may indicate that more motor units can recover while others are recruited to move submaximal weight, thereby delaying fatigue.

Many equations exist for calculating 1RM values based on submaximal loads lifted to fatigue. LeSuer, McCormick, Mayhew, Wasserstein, and Arnold (1997) evaluated the accuracy of seven equations for the bench press, squat, and deadlift (the three powerlifts), in untrained college students. The formula derived by Mayhew, Ball, Arnold, and Bowen (1992) was most predictive of bench press 1RM whereas the formula from Wathen (1994) was most predictive of squat and deadlift 1RM.

Mayhew et al. (1992) equation: 100*weight/ (52.2+41.9*exp[-0.055*reps]) = 1RM

Wathen (1994) equation: 100*weight/ (48.8+53.8*exp[-0.075*reps]) = 1RM

LeSuer et al. (1997) recruited untrained participants so is likely not optimal for application to those who are trained, as trained individuals often can perform less repetitions to fatigue at 90% than untrained individuals (Ware, Clemens, Mayhew, & Johnston, 1995). However, currently it appears that, no review exists for 1RM equations specifically of highly resistance trained individuals. It is interesting to note that the formula derived from Mayhew et al. (1992) was used for “touch and go” bench press rather than paused bench press (which is what was used in the present study). However, LeSuer et al. (1997) performed their validation study in regards to paused bench press and still found the Mayhew et al. (1992) equation to be most accurate at determining 1RM bench press strength from repetitions to fatigue.

2.4 Training for Maximal Strength Gain

Well-trained athletes should utilise loads of high intensity and low repetitions within a training programme when the goal is to increase maximal strength (Sale, Martin, & Moroz, 1992). This allows development of the nervous system so it can become more efficient at co-ordination and recruitment of muscle fibres to assist the movement. These low repetitions can be characterised by six or less repetitions per set which facilitates a training intensity of ~85% during strength phases according to the meta-analysis by Peterson et al. (2004). Zourdos (2012) states powerlifters would probably benefit from training in the one to three repetition range which coincides with recommendations by Shimano et al. (2006) who state training above 90% 1RM should be used for strength gains in free weight exercises.

A table designed by highly successful Russian Olympic weightlifting coach, Alexandre Priplepin, provides an applicable method of developing maximal strength (table 2.3). Prilepin's table describes how many repetitions should be performed per set for a given total intensity and has been applied by other researchers for example Hammer (2009).

Table 2.3. *Prilepin's Table*. Adapted from Hammer (2009).

Absolute load (%)	Repetitions per set	Optimal volume (repetitions)	Volume range (repetitions)
60-69	4-6	24	18-30
70-79	3-6	18	12-24
80-89	2-4	15	10-20
>90	1-2	7	4-10

Moreover, higher repetition training should still be included in a programme designed to improve maximal strength. Moderate intensity training within the 60-80% 1RM range can result in greater peripheral metabolic fatigue causing greater recruitment of large (fast) motor units and may be responsible for the greater hypertrophy in bodybuilders versus powerlifters (Schoenfeld, 2013). Recommendations by Fleck and Kraemer (2004) state that hypertrophy is optimised with loads of 6RM-12RM. Muscular hypertrophy can facilitate gains in maximal strength after neural adaptations have taken place (Peterson et al., 2004). Jones and Rutherford (1987) stated that hypertrophy in type II muscle fibres could increase the force per unit area of muscle. This is a major determinant of skeletal muscle strength (Jones and Rutherford, 1987), as a greater cross sectional area (CSA) of muscle can facilitate future strength improvements (Zourdos, 2012). Thus incorporating training directly aimed at hypertrophying muscle fibres should not be overlooked even if the aim is focused on maximal strength improvements. Lower repetition phases of training will still evoke muscular hypertrophy to a degree, but higher repetition training may be more efficient and also conveniently allow a transition from higher volume, lower intensity training to lower volume, higher intensity in a periodised design.

For maximal strength gains in trained individuals Peterson et al. (2004) has recommended a volume of eight sets per muscle group per week split into two separate occasions. If the goal of a training programme is to improve maximal strength for squat, bench press, and deadlift, the assistance exercises will need to be carefully selected to strengthen the muscles associated with these movements and prevent imbalances, and therefore injuries, occurring. The ACSM (2013) recommends a focus of multi-joint exercises for example shoulder press, dips, and pull-ups. They also recommend single joint exercises to prevent muscle imbalances; for example, abdominal crunches and leg curls to strengthen the opposing muscles involved in the dead lift and squat, respectively.

The research conducted in this thesis was built from undertaking a comprehensive review of the current literature, which is summarised in Chapter Two. Chapter Two provided insights on the physiological responses to resistance training and the types of periodised programmes and their prescription for resistance training, although equivocal findings have made it difficult to determine the appropriate periodised programme for maximal strength improvements. Further, AR training is a popular training method that may allow for greater gains in strength due to fine tuning of the fatigue-fitness interaction. Additionally, there is scant research on the best method to increase maximal strength in in trained individuals when comparing AR with a standard periodised programme. Therefore, in the following study, we compared a TD programme with a load AR programme on maximal strength gain in trained individuals.

Chapter 3 – Research Aim and Hypotheses

The aim of this study was to examine whether a load-autoregulated strength training program is more effective in improving maximal strength in the squat, bench press, and dead lift than a traditionally periodised program, in experienced weight-trained individuals.

It was hypothesised that AR programming would facilitate greater maximal strength improvements than TD due to a finer control of the fatigue-fitness interaction over time as well as by ensuring individualised strength progression.

Chapter 4 – Methods

4.1 Overview

Following recruitment, participants were required to attend a familiarisation session. Height was measured, and the participants were explained protocol details. Two weeks later, baseline measures (B1 and B2) of one-repetition-maximum (1RM) were obtained. Participants were randomly assigned to start with the AR training programme or TD within which they completed eight weeks of training followed by final testing (F1 and F2). Two participants withdrew due to injury unrelated to the study. This resulted in five participants started the TD programme and three started with the AR programme. The study was of cross-over, randomised design.

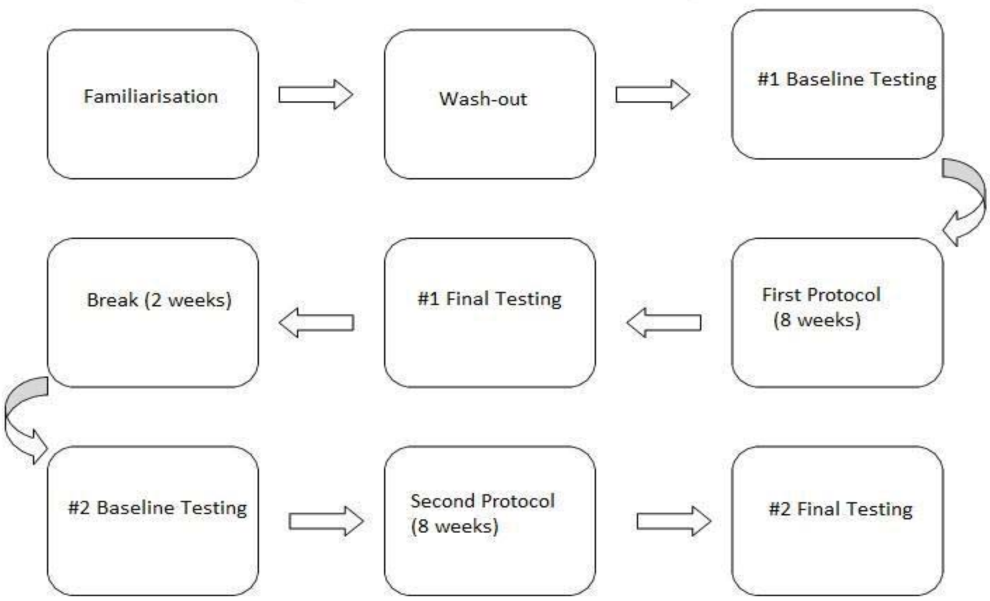

Figure 4.1. Timeline of experimental protocol

Between F1 and the commencement of B2 for the second programme, participants trained to their own previous methods for one week and then one wash out week was undertaken the week before B2 testing. F2 was conducted following the second training block of eight weeks.

The total number of times each participant attended the laboratory for familiarisation or 1RM testing trials was thirteen.

4.2 Participants

Ten healthy weight-trained males volunteered to participate in this study. Two did not complete the study due to injury and data obtained from these participants was excluded in description and analysis. Characteristics of participants were mean age 24.0 ± 4.9 years (mean ± standard deviation (SD)), weight 84.3 ± 9.7kg, and height 180.9 ± 6.3cm. Participants had consistently weight trained (at least 2 times per week) for the past 2.7 ± 1.3 years prior to recruitment, within which they had consistently executed (at least 1 time per week) the barbell squat, barbell bench press, and barbell deadlift for 1.9 ± 1.2 years. Participants were instructed not to participate in competitive sport during the time frame of the study. Participants were recruited through word of mouth and advertisement through the Massey University Recreation Centre. All participants were given an information sheet (Appendix A) and completed a health screening questionnaire (Appendix B) prior to participation in this study (see appendices). Those who were deemed suitable for the study gave informed, written consent (Appendix D). This study was approved by the Massey University Human Ethics Committee.

4.3 Experimental Protocol

4.3.1 Familiarisation Session

In week one, participants were shown where they were to perform their 1RM trials. Details of training history (Appendix C) were recorded. Participants were health screened, shown how to calculate AR training load, and given an explanation of other protocol details for example how to input their training data online. They were informed of the criteria for a successful lift of the squat, bench press, and deadlift during all 1RM testing sessions.

4.3.2 Wash-Out Period

Week two served to equalise fatigue states so that all participants came into the baseline testing week refreshed. Participants reduced training load and sets per exercise by 50% of their usual training for that week. This wash-out period ideally would have been elongated to ensure residual fatigue and strength levels were at a true baseline, however the length of the study was already exceedingly long and so an extra burden of time commitment on the participants was not feasible.

4.3.3 Baseline Measures

Participants were required to establish a 1RM in the barbell squat, bench press, and dead lift. This was carried out under supervision at the Human Performance Laboratory of the Practical Teaching Complex in the School of Exercise Science at Massey University, Palmerston North. Three separate days were scheduled within the same week for participants to complete this (one exercise per day) as to facilitate reliable baseline strength values (Prestes et al., 2009a). In most cases, testing days were separated by 48 hours but occasionally participant's schedules did not allow this. In the circumstance that testing periods were only separated by 24 hours, however the same conditions were replicated in the final testing for the particular participant.

Following a warm-up, participants established a 1RM according to the guidelines specified by American College of Sports Medicine (2013). The warm up consisted of a number of submaximal repetitions of the exercise that was to be tested. For example for the bench press: five repetitions of the bar only, three repetitions at a slightly heavier load, and two repetitions at a load heavier but still submaximal. A weight 50-70% of the participant's perceived capacity was then used for a single repetition. Load was adjusted upwards until a true 1RM (successful lift within the technique specifications for each lift) was found within three more trials. Three to five minutes rest was given to allow intramuscular adenosine tri-phosphate and phospho-creatine stores to be replenished (Fleck & Kraemer, 2014); this rest time was self-selected by participants. B1 strength levels for the participants were: 116.3kg ±18.9kg squat, 90.6 ± 9.2kg bench press, 158.8 ± 23.9kg deadlift, summating to a 365.6 ± 44.5kg total.

4.3.4 Criteria for a Successful Lift

The squat was completed to a depth where the top of the patella was in line or below the hip crease followed by the participant standing up with knees and hips fully extended. The bench press required lowering of the bar to the chest where it was paused for one second before being pressed upwards and elbows extending fully at the top. The head, upper back, buttocks, and feet were to remain in contact with the bench (or ground for the feet) at all times during the lift. In the deadlift the participant was required to stand up with the barbell to a fully erect posture without hitching the bar up the thighs. All lifts were completed without any downwards movement of the barbell during the concentric phase of the lift according to the guidelines described by the International Powerlifting Federation (2015).

4.3.5 Programme Outline

The study was randomised, cross-over design. The following outline is applicable to the training of the 3 main lifts completed under this protocol once per week. Squats were completed on Mondays, bench press on Wednesdays, and deadlifts on Fridays.

The protocol for both programmes followed the schedule below:

Week 1: Familiarisation

Week 2: Wash out

Week 3: Baseline 1RM testing

Week 4: 1 set of AMRAP @ 85% 1RM then 2 sets x 10 reps @ 65% of 1RM established at baseline (TD) or on a daily basis from AMRAP (AR)

Week 5: 1 set of AMRAP @ 85% 1RM then 2 sets x 10 reps @ 72.5% of 1RM

Week 6: 1 set of AMRAP @ 85% 1RM then 3 sets x 6 reps @ 77.5% of 1RM

Week 7: 1 set of AMRAP @ 85% 1RM then 3 sets of 4 reps @ 82.5% of 1RM

Week 8: 1 set of AMRAP @ 85% 1RM then 4 sets of 3 reps @ 85% of 1RM

Week 9: 1 set of AMRAP @ 85% 1RM then 3 sets of 3 reps @ 87.5% of 1RM

Week 10: 1 set of AMRAP @ 85% 1RM then 3 sets of 2 reps @ 90% of 1RM

Week 11: 1 set of AMRAP @ 85% 1RM then 3 sets of 1 rep @ 95% of 1RM

Week 12: Post 1RM testing

Table 2.3. (Prilepin's table) provided a basis to programme sets following the 85% AMRAP set for the final six weeks of each programme as discussed in Chapter Two. Warm-up sets prior to working sets consisted of 1 set of 5-10 reps with an unloaded bar, followed by 2-4 subsequent sets of ascending loads with decreasing repetitions. Each protocol required participants to complete one AMRAP set, this served as the first working set so that this training stimulus was the same for each protocol and, in the case of AR, served to determine the days training load. Rest time advised was between 3-5 minutes, and was self-selected. Participants completed AMRAP with 85% of their measured baseline 1RM and then, using the chart provided, calculated their daily training load (Appendix F). The equations used for the chart are given below. The training load was applied in an AR manner based on each day's fatigue/fitness level.

Bench press: Mayhew et al. (1992) equation: 100*weight/(52.2+41.9*exp[-0.055*reps]) = 1RM

Squat and deadlift: Wathen (1994) equation: 100*weight/(48.8+53.8*exp[-0.075*reps]) = 1RM

(exp represents the base of natural logarithms)

Justification of using of the equations above is discussed is Chapter Two. Two excel chart of weights lifted for a given number of repetitions to predict 1RM, based on the previous two equations, was given to participants to use during training sessions.

4.3.6 Assistance Exercises

Assistance work was completed following the main exercise for each day.

Table 4.1. *Assistance exercises prescribed following main exercise*

Monday	Wednesday	Friday
Leg Press 3x6	Incline Barbell Bench Press 3x6	Pull-down 3x6
Leg Curl 3x12	Military Press 3x6	Barbell Row 3x6
Crunch 3x12	Triceps Extension 3x12	Biceps Curl 3x12

These exercises were completed in the first week with a weight which achieved within one to two repetitions shy of fatigue on the last set. This weight was static for the first four weeks of each programme and then increase 5% for the second four weeks of the each programme. Exercises involving smaller amounts of musculature were prescribed at a lower intensity so that form could be maintained without larger muscle groups taking control of the movement. Shorter rest periods of one to two minutes were be employed for these movements.

4.3.7 Training Diary & Participant Monitoring

Participants were given an online training diary (Appendix E) within which they recorded details such as number of repetitions obtained during the AMRAP sets, rating of perceived exertion through perceived repetitions left until fatigue, sets where they were unable to complete the prescribed repetitions, and additional information about other physical exercise they did in the week. This data was directly input into the diary during the training session or recorded on paper and then input by the end of that week. At least one training session per week for each participant was supervised to reinforce safe technique and ensure adherence to protocol. The particular training session that this is was alternated weekly. For example, participant one had their squat session monitored in week one and then their bench press session monitored in week two.

4.3.8 Diet Control

Participants recorded their diet prior to testing on testing day and replicated this for final testing of the same exercise. They gave the data to the researcher at baseline testing who then reminded them to repeat consumption of the particular food/drink in the subsequent testing period of the same exercise. No food was to be consumed within two hours from testing. Participants were told to refrain from stimulants or alcohol 12 hours prior to testing. Participants were weighed prior to each 1RM trial.

4.3.9 Participation Compensation

Participants were compensated with $250 each upon completion of the study. Participants who withdrew during the study were given a suitable proportion of $250 based on how long they participated in the study. This compensation was to cover the possible extra time they spend training as well as petrol to and from the 1RM testing facility.

4.4 Statistical Analysis

Statistical analyses were conducted by IBM SPSS statistics software (version 20.0, IBM Corp, NY, USA). A series of repeated measures analysis of variance (ANOVA) were performed to identify changes in the main effects of time (B1 versus B2 and F1 versus F2), programmes (TD vs AR), and the time x programme interaction for body weight, maximal strength performance (squat, bench press, deadlift, and combined total) and order effect (trial 1 vs trial 2 for squat, bench press, and combined total). When significant main effects were observed, post hoc analysis was performed using Bonferroni adjustment. Raw data was used for analysis. Significance level was set at $p \leq 0.05$. Data is presented as mean ± standard deviation (SD). Additional statistical analyses are outlined below.

4.4.1 Formula validation

The accuracy of the utilised equations: Mayhew et al. (1992) for the bench press, and Wathen (1994) for the squat and deadlift, at predicting suitable 1RM loads for this population during the AR programme was examined for each of the three powerlifts (squat, bench press, deadlift) separately. Data for B1 1RM was compared to predicted 1RM from week one trial one (W1T1). Additionally, data for F1 1RM was compared to predicted 1RM from week eight trial one (W8T1). These analyses were performed through multiple paired t-tests, as well as Pearson correlation coefficients. The results of the analyses were interpreted with the underlying assumption that participants' performance would not have significantly changed between baseline tests and week one AMRAPs, or between week eight AMRAPs and final tests. These methods of formula validation were assumed to be a more accurate way of formula validation than performance of an AMRAP set following each 1RM test, due to the acute fatigue caused by 1RM testing.

4.4.2 Training Volume

A paired t-test was conducted to assess total volume completed for each of the three powerlifts in each programme. Using data from each training session, volume was calculated using the following formula where AMRAP load refers to 85% of baseline 1RM and working load refers to the load used in the subsequent sets.

$$Volume = (AMRAP\ load\ x\ reps) + (working\ sets\ x\ repetitions\ x\ working\ load)$$

4.4.3 Training Intensity

Repeated measures ANOVA were performed to compare 1RM used to prescribe training load for each of the powerlifts over time (weeks 1 to 8) and between programmes (TD vs AR).

4.4.4 Maximal Strength Performance

In addition to repeated measures ANOVA, ES were calculated for change in 1RM for each powerlift through the following formula:

$$Effect\ size = Absolute\ performance\ change/mean\ SD$$

Where absolute performance change refers to the difference in 1RM (kg) between baseline and final testing and mean SD refers to the average SD at baseline and final time points. The magnitude of these changes is referenced to Table 2.1. Trivial = <0.35, small = 0.35-0.80, moderate = 0.80-1.50, large = >1.50 (Rhea, 2004) .

4.4.5 Submaximal Repetition Performance

Repeated measures ANOVA were performed to compare number of repetitions completed during AMRAP sets for each of the powerlifts over time (weeks 1 to 8) and between programmes (TD vs AR).

Chapter 5 – Results

5.1 Bodyweight

Body weight significantly changed over time (p=0.043) but it was not different between programmes (p=0.457) or programme x time interaction (p=0.490). Body weight changed from 84.9 ± 9.8kg to 86.2 ± 10.4kg in the TD programme, and from 84.5 ± 10.0kg to 85.4 ± 10.0kg in the AR programme.

5.2 Formula Validation

Comparisons made between B1 achieved 1RM and W1T1 predicted 1RM, and F1 achieved 1RM and W8T1 predicted 1RM, revealed insignificant differences (p<0.05) for all exercises except for deadlifts F1 versus W8T1 (refer to Table 5.1 and 5.2). Pearson's correlation coefficients of 0.93-0.97 indicate strong correlations between achieved and predicted 1RM.

Table 5.1. *Formula validation 1.*

B1 versus W1T1					
Lift	Achieved 1RM (kg)	Predicted 1RM (kg)	Difference	P-value	Pearson's correlation coefficient (r)
Squat	116.3 ± 18.9	118.1 ± 25.2	+1.8	**0.544**	**0.97**
Bench press	90.6 ± 9.2	92.5 ± 11.8	+1.9	**0.170**	**0.97**
Deadlift	158.8 ± 23.9	156.9 ± 28.3.1	-1.9	**0.549**	**0.96**

Table 5.2. *Formula validation 2.*

F1 versus W8T1					
Lift	Achieved 1RM (kg)	Predicted 1RM (kg)	Difference	P-value	Pearson's correlation coefficient (r)
Squat	128.8 ± 20.9	132.2 ± 26.7	+3.4	**0.264**	**0.97**
Bench press	94.1 ± 8.8	95.9 ± 9.7	+1.8	**0.170**	**0.93**
Deadlift	169.4 ± 20.8	182.2 ± 29.7	+12.8	**0.019**	**0.95**

5.3 Training Volume

Training volume did not differ between treatments for any of the three powerlifts (Table 5.3).

Table 5.3. *Volume performed in the squat, bench press, and deadlift, for each programme.*

Programme	TD volume (kg)	AR volume (kg)	P-value
Squat	15,374 ± 3308	16,697 ± 4417	0.51
Bench press	11,347 ± 1613	11,237 ± 1437	0.75
Deadlift	21,143 ± 2916	21,815 ± 4342	0.44

5.4 Training Intensity

Training intensity described as 1RM used to dictate training load was significantly greater in the AR training programme for each powerlift (all treatment x time interactions = $p<0.05$) (figures 5.1, 5.2, and 5.3).

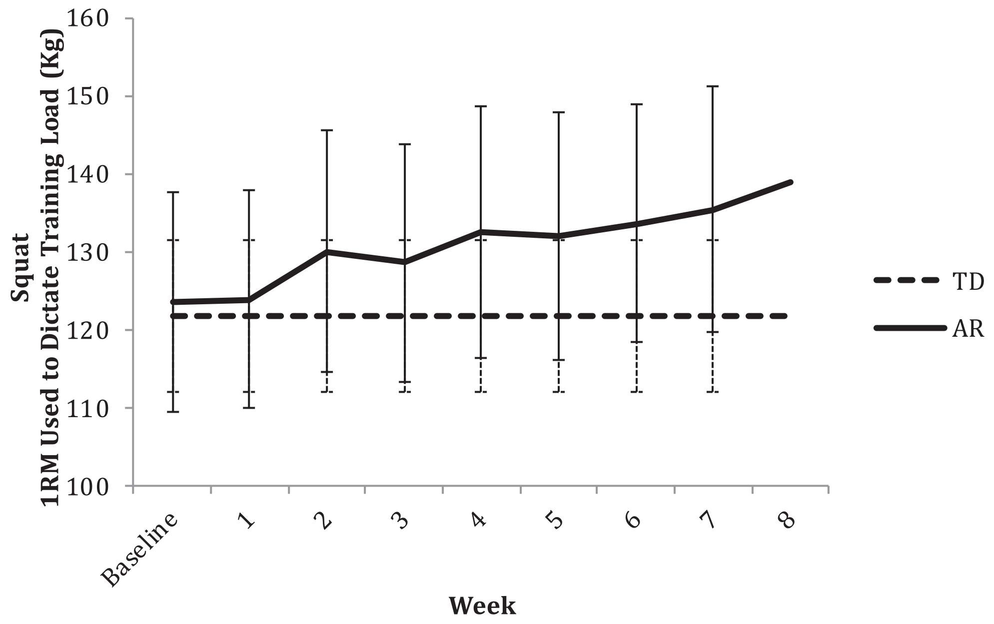

Figure 5.1. 1RM used to prescribe training load for the squat.

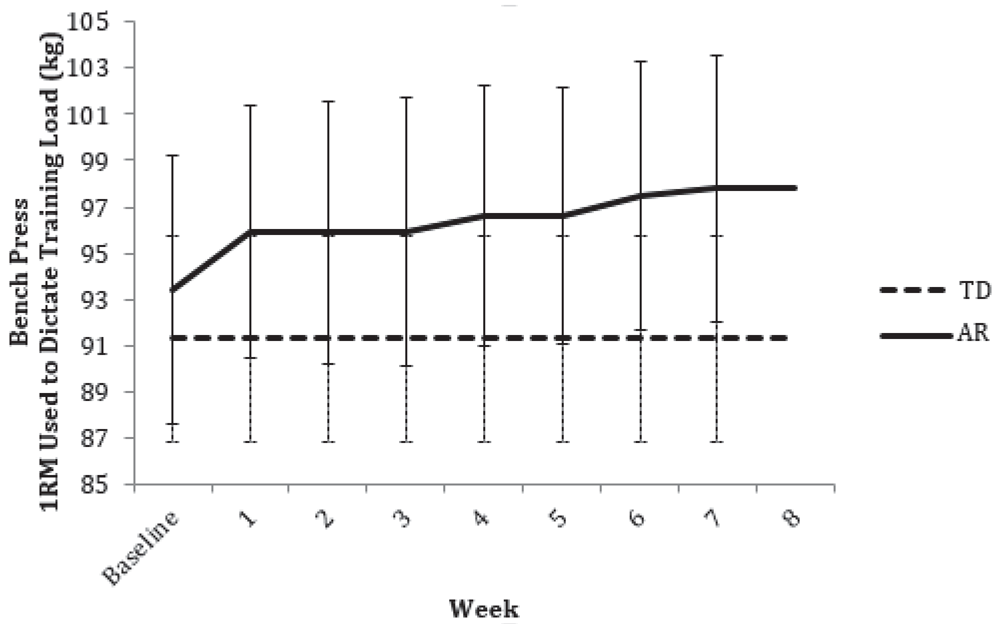

Figure 5.2. 1RM used to prescribe training load for the bench press.

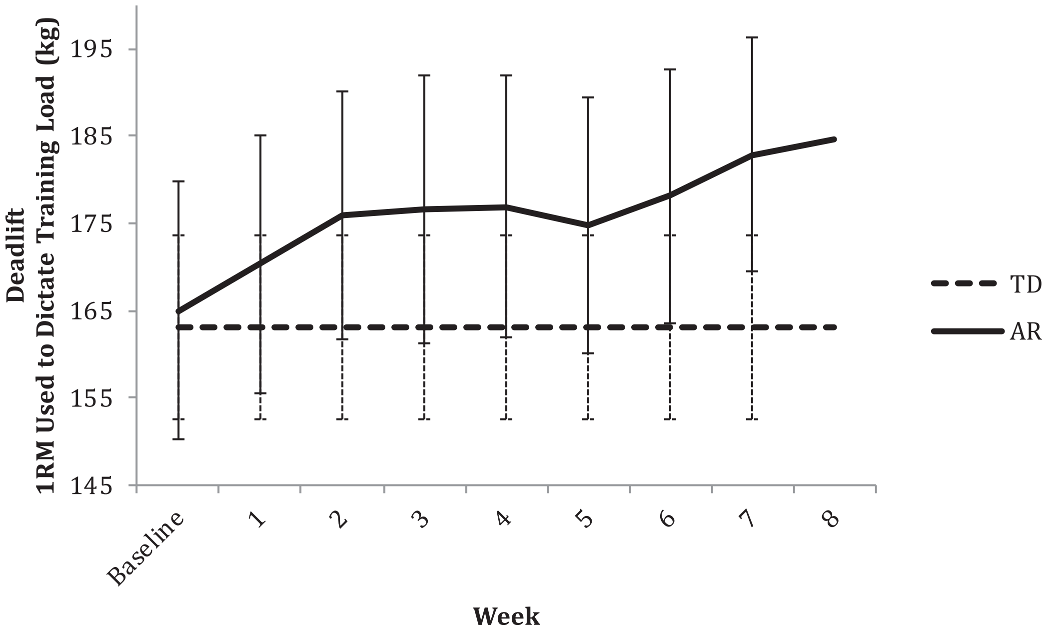

Figure 5.3. 1RM used to prescribe training load for the deadlift.

5.5 Maximal Strength Performance

Significant time (all p<0.05) effects were present for squat, deadlift, and total. Additionally, no differences were present between programmes (all p>0.05) for the squat, deadlift, or total. For the bench press, changes in 1RM over time approached significance (p=0.064). No treatment effect was found (p=0.871). However, a programme x time interaction (p=0.020) was observed and post-hoc analysis revealed a significant difference between baseline and final with TD (p=0.014).

Table 5.4. *1RM for each powerlift at baseline and following each programme.*

Programme	TD Baseline (kg)	TD Final (kg)	Difference (kg)	AR Baseline (kg)	AR Final (kg)	Difference (kg)
Squat	121.6 ± 18.2	131.6 ± 19.2	**10.0**	123.8 ± 22.8	133.4 ± 19.7	**9.7**
Bench press	91.3 ± 9.0	95.3 ± 8.8	**4.1***	93.4 ± 10.3	93.8 ± 10.8	**0.3**
Deadlift	161.3 ± 21.0	171.3 ± 17.3	**8.1**	165.0 ± 26.0	173.1 ± 21.5	**8.1**
Total	375.9 ± 41.0	398.1 ± 40.1	**22.2**	382.2 ± 51.9	400.3 ± 46.0	**18.1**

* Significantly greater improvement ($p<0.05$).

These results are supported by the ES illustrated in table 5.5.

Table 5.5. *Effect size for each exercise and total for each programme and their magnitude.*

Programme	TD ES	Magnitude of ES	AR ES	Magnitude of ES
Squat	0.53	Small	0.46	Small
Bench press	0.46	Small	0.03	Trivial
Deadlift	0.42	Small	0.34	Trivial
Total	0.55	Small	0.37	Small

5.6 Submaximal Repetition Performance:

Significant time (all $p<0.05$) effects were present for all three powerlifts (as illustrated by figures 5.4, 5.5, 5.6) indicating AMRAP set repetitions increased as each training programme progressed. AMRAP set results did not differ by programme or programme x time (all $p>0.05$).

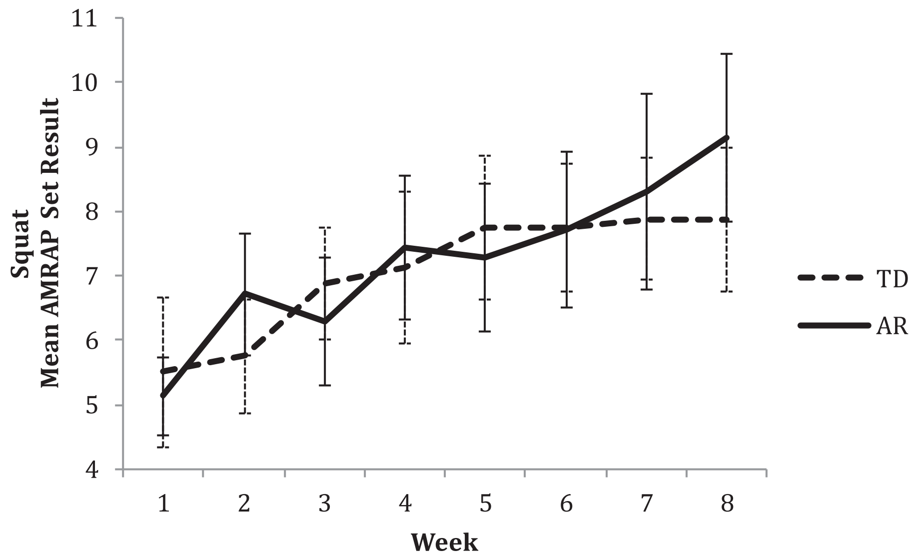

Figure 5.4. AMRAP performance in the squat.

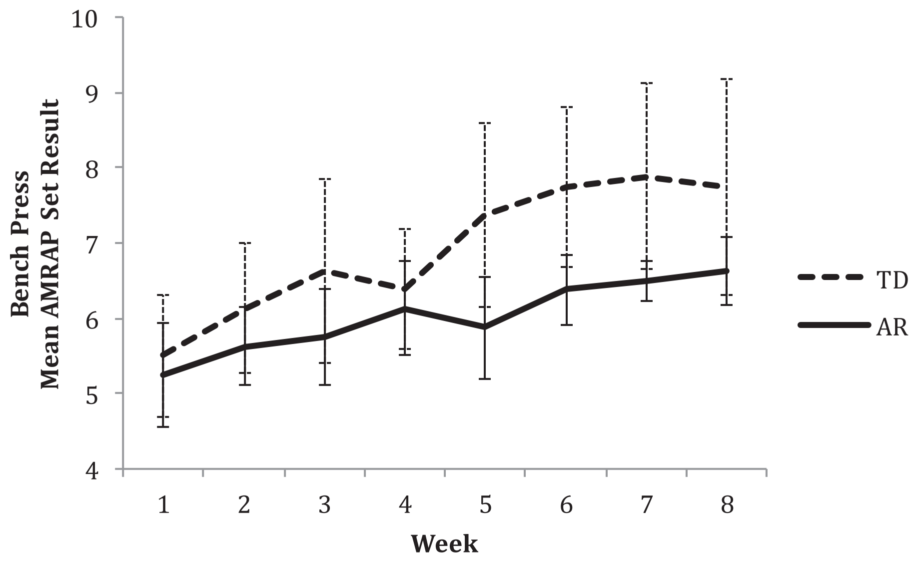

Figure 5.5. AMRAP performance in the bench press.

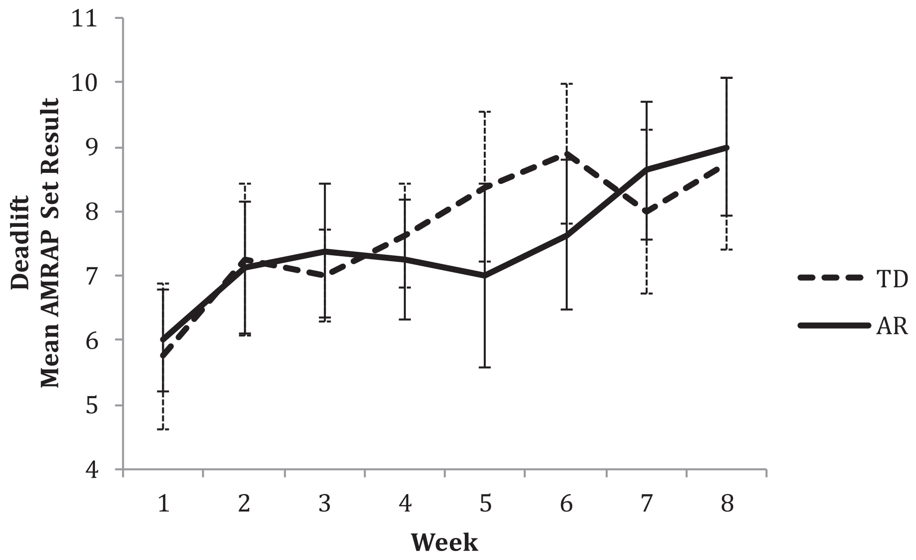

Figure 5.6. AMRAP performance in the deadlift.

5.7 Order Effect of Training

Order effects were not present for the squat, bench press, or deadlift when examined individually (p=0.085, 0.170, 0.170 respectively). However, there was a significant time x order effect for total (p=0.035) which improved 26.6 ± 12.9kg on the first trial, but only 13.8 ± 9.4kg on the second trial.

Chapter 6 – Discussion

The aim of the study was to compare an AR load progression to a traditional load progression over the course of two eight week training cycles, with the goal of improving strength in the barbell squat, bench press, and deadlift. AR load used per session was controlled through a set to fatigue using 85% of baseline 1RM and then utilising a 1RM calculation. This value was used to prescribe the load for the following sets of that exercise for that training session. The hypothesis that AR programming would facilitate greater maximal strength improvements than TD due to a finer control of the fatigue/fitness interaction over time was not realised.

6.1 Primary Performance Measure: Maximal Strength.

The primary measure of this study was performance of 1RM squat, bench press, deadlift, and the total summation of these lifts. Significant time effects revealed participants improved in the squat, deadlift, and total over the course of the study. There were no differences in the effectiveness of each programme at improving maximal squat, deadlift, or total strength.

The time effect for bench press was insignificant, yet approaching significance ($p = 0.064$). This may have been due to the low frequency and therefore volume of work performed for the chest, shoulders, and triceps compared to that of the lower body. Recommendations for training frequency according to Wernbom, Augustsson, and Thomeé (2007) are for two to three times per week per muscle group for hypertrophic gain, which enhances potential for strength development (Peterson et al., 2004). Within this study, participants only trained the bench press muscles once per week compared to the hip and knee extensor muscle groups used for the squat and deadlift that were trained twice per week. Although there was no time or treatment effect for the bench press, there was a programme x time effect in favour of the TD programme producing greater gains (Table 5.4.). This notion was supported by the ES between the two (0.46 versus 0.03) as illustrated in Table 5.5; this is contrary to the findings of Mann et al. (2010) (Table 2.2) who reported AR training to be superior to LP in maximal bench press strength (ES of 0.83 versus 0.00 respectively). This may have been due to the lighter, and perhaps easier feeling, loads utilised for the bench press in the TD programme (figure 5.2.) which may have given the participants greater confidence for final testing. However, the squat and deadlift improvements were similar between programmes despite utilisation of greater loads in the AR programme as discussed in section 6. 1. 2. It may have also been due to the limited experience that the participants had in the pause on the bench press, perhaps causing a subtle learning effect in favour of the TD programme as discussed in section 6. 1. 3.

ES calculations for each powerlift revealed small average ES of 0.50 for the squat and 0.38 for the deadlift, and a trivial 0.25 ES for the bench press. These ES are relatively small compared to studies reviewed in Table 2.2. Several studies examined squat and bench press 1RM performance gain in trained males utilising different periodisation styles with moderate to large ES (Baker et al., 1994; Mann et al., 2010; Peterson et al., 2008; Willoughby, 1992). However, these studies were at least 12 weeks in length (the present study being 8 weeks) with the exception of Mann et al. (2010), a longer duration may produce greater gains. The low ES in the present study may have been due to the low training frequency and volume performed relative to other studies. For example Baker et al. (1994) and Mann et al. (2010) had participants complete multiple bench press and squat sessions per week, facilitating greater frequency, volume, and thus overload and adaptation of the neuromuscular systems.

6.1.1 Training Volume

Training volume was not significantly different between the programmes in this study for any of the powerlifts. This was achieved through utilising the same number of total sets per muscle group over the course of each training cycle and may be a factor in determining the lack of difference between the programmes for the squat and deadlift. Other studies (Baker et al., 1994; Hoffman et al., 2009; Peterson et al., 2008) have reported that maximal strength improvements were similar between periodisation styles when volume was matched. Both Rhea et al. (2002) and Monteiro et al. (2009) discovered UP to be superior to LP in maximal strength improvements in both the bench press and the squat when volume was matched. Thus the interaction and timing between intensity and volume within a periodised programme are influential on strength gain.

6.1.2 Training Intensity and Formula Validation

Training intensity described as load utilised to prescribe training load versus baseline 1RM, was significantly greater in the AR programme for all three powerlifts as shown by figures 5.1 – 5.3. This resulted in the stimulus that we sought for: variations in weekly training performance dictating load utilised in the training session. However, the maximal strength outcome of the study was not favourable for AR despite greater load used in training.

The formulae provided by Mayhew et al. (1992) (for the bench press) and Wathen (1994) (for the squat) were suitable in part, for training the current population. Although, predicted 1RM provided by the Wathen (1994) equation in W8T1 was significantly higher than achieved 1RM in final testing 1 for the deadlift. This resulted in participants using unnecessarily high loads for the deadlift training sessions near the end of the AR programme. An upwards shift of load utilised for the AMRAP set around the middle of the training programme could have been beneficial in order to ensure AMRAP set results remain in a more favourable range to predict 1RM (LeSuer et al., 1997).

6.1.3 Order Effect of Training

The first trial that the participants performed produced significantly greater improvements in total, in either programme. This could have been due to participants not being accustomed to the technique specifications. Approximately half of the participants were not completely comfortable with squatting to suitable depth (where the hip crease is in line or slightly below the top of the patella). As such, low B1 1RM squat values would have ensued. Participants were also not accustomed to the pause on the bench press. Despite no significant differences in order effect for either the squat or the bench press, a subtle learning effect was likely present for each which caused the order effect for total.

The study design was meant to be a randomised, matched crossover, however for unrelated reasons, two participants discontinued the study, this leaving the study design unmatched with five participants completing the TD programme as their first trial and three in the AR programme. This may have exacerbated a significant order effect thus biasing results in favour of the TD programme.

6.2 Long Term Progress

Despite the lack of difference between programmes, informal conversation with participants revealed that the AR programme was more enjoyable. Participants explained that they enjoyed being able to have the authority to influence the training load based on how they performed on a particular day. Also, the motivation of having the opportunity to surpass previous "personal records" was a motivating factor for the participants. Based on this speculation that AR may increase enjoyment and have a positive influence on programme adherence, there is a possibility that AR training performed over a longer term may facilitate greater gains.

For trainees less skilled at performing an accurate 1RM test, AR training may be more applicable. If 1RM testing is conducted inappropriately, for example if much warm-up volume is too high, or there is inadequate rest between attempts, 1RM values obtained could be misrepresentative of true 1RM strength. This would result in inappropriate training load and perhaps suboptimal training prescription for multiple months. Therefore, employing some form of autoregulation would likely be useful in this instance.

6.3 Limitations

The lack of stimulus of the bench press musculature resulted in no time effect of training. In hindsight, an additional bench press workout could have been added to each programme. However, this may have complicated the study and reduced adherence rates. The prescription of AMRAP sets every training session also was mentally demanding for the participants as discussed in informal conversations. It is also exceedingly difficult to plan a training programme which can be controlled between participants but also provides enough training stimulus without overreaching occurring at undesirable times.

A larger wash-out period prior to commencement of the study and between programmes would have been a better methodology. This would ensure that fatigue and fitness states were at a true baseline before baseline testing. However, as described previously, this was not feasible in this study due to excessive participant burden with relation to time commitments.

Another limitation of this study was that not all training sessions were monitored. It is possible that some participants strayed from exact protocol during the course of the study. The time that would be spent monitoring every single training session (384 training sessions excluding participants who discontinued the study) was too much for the scope of this research.

6.4 Future Research

This study design could be incorporated into a new study with some modifications to allow volume AR. Many methods of AR training involve volume AR through total set number manipulation, as well as intensity adjustments (Tuchscherer, 2008). Elite powerlifters who are familiar with the use of the RIR scale could be an interesting population to include in AR strength training research, due to their ability to accurately judge RIR (Hackett et al., 2012).

Ideally, more participants would be included into a programme of this design. Longer study duration could also be useful to examine longer term effectiveness of AR style training. However, much care would need to be taken when selecting and monitoring participants. Future research would ideally use more trained participants to reduce the order effect, or at least be conducted within more flexible dates to allow extra participant recruitment if the design becomes unmatched due to drop-outs.

Chapter 7 – Conclusion

Few studies have investigated AR style training on maximal strength gain in healthy, trained males. Consequently, the aim of this study was to investigate the effect of an eight week strength training programme with load AR each training session, compared to a TD programme with load planned prior to the first week of the programme. The study was of cross over design with a two week wash-out period between. Despite a sound theoretical basis that could favour AR style training, no differences between effectiveness of each programme in the squat, bench press, or total. The TD style programme was more effective at improving bench press strength. However, this study only applied AR to load prescription and as such volume was not different between programmes.

Several limitations impeded the interpretation of the results of this study: a significant order effect was present for total, not all training sessions were monitored, and the wash out periods were not very long. Practical application of results from this study would include recommendations to include some form of volume autoregulation within a programme design as described by Tuchscherer (2008). Ultimately, an effective programme design should utilise sound scientific principles while also ensuring training enjoyment, to facilitate greater protocol adherence and long term progression.

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List of Appendices

Appendix A

Participant Information Sheet

A comparison between a traditional periodised programme and a load autoregulated periodisation programme for maximal strength gain in the squat, bench press, and deadlift in weight-trained males

INFORMATION SHEET

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This study is carried out with the intention of fulfilling the requirements of a Master of Science in Exercise and Sport Science for Jeremy Fraser.

You are invited to participate in this study which will compare different programming methods with the goal of improving maximal strength in the squat, bench press, and deadlift.

Introduction:

Training towards the goal of improving maximal strength is commonly undertaken, particularly by athletes involved in contact sports, powerlifters, and recreational body builders. Traditional periodised strength plans manipulate intensity as a percentage of one-repetition-maximum, this maximal value is obtained prior to the beginning of the training cycle. However, there are day to day fluctuations in strength, due to fatigue and improving fitness levels which may affect the accuracy of prescribing training based off this one-off maximal value. Some training days may not provide enough stimulus for optimal adaptation, whereas others may provide too much stimulus resulting in too much fatigue than desired for a particular stage in the training phase. This provides a basis for programmes to use auto-regulation (AR) as it allows an individual to increase strength at their own pace. Currently, only one study exists in the literature with regards to AR training in healthy athletes. Thus, this study aims to expand on the apparent gap within periodisation literature, specifically with regards to maximal strength in the squat, bench press, and deadlift.

Participation:

Participants will be recruited via word of mouth and advertisement within the Massey University Recreation Centre. We are recruiting twelve healthy males aged between 18 and 45 who have been involved in regular resistance exercise for the past two years within which they have performed the barbell: back squat, flat bench press, and deadlift, one time per week for the past year. All participation if voluntary and you may withdraw from the study at any time. You must be a member of the Massey University Recreation Centre so that appropriate training monitoring can occur. Membership is not provided by participation in this study.

Methodological Details:

Overview

Following recruitment, you will be required to attend a familiarisation session where the protocol details will be explained to you. Two weeks later, baseline measures of one-repetition-maximum (1RM) will be obtained. 1RM is the maximal load that can be lifted in a particular fashion within the confines of the criteria of that particular lift. You will be randomly chosen (six per group) to start with the AR training programme or the traditional training programme within which you will complete eight weeks of training followed by final testing. Both programmes have a back bone of linear periodisation. The study will be of cross-over, randomised design. Between the first and final testing and the commencement of baseline testing for the other program, you will be given a two week break during which training load and volume will be reduced. A second final testing will be conducted following the second training block of eight weeks. The total number of times you will attend the laboratory for familiarisation or 1RM testing trials is thirteen. Height will be taken during the initial baseline session, and bodyweight will be recorded during both baseline and final testing sessions of each protocol.

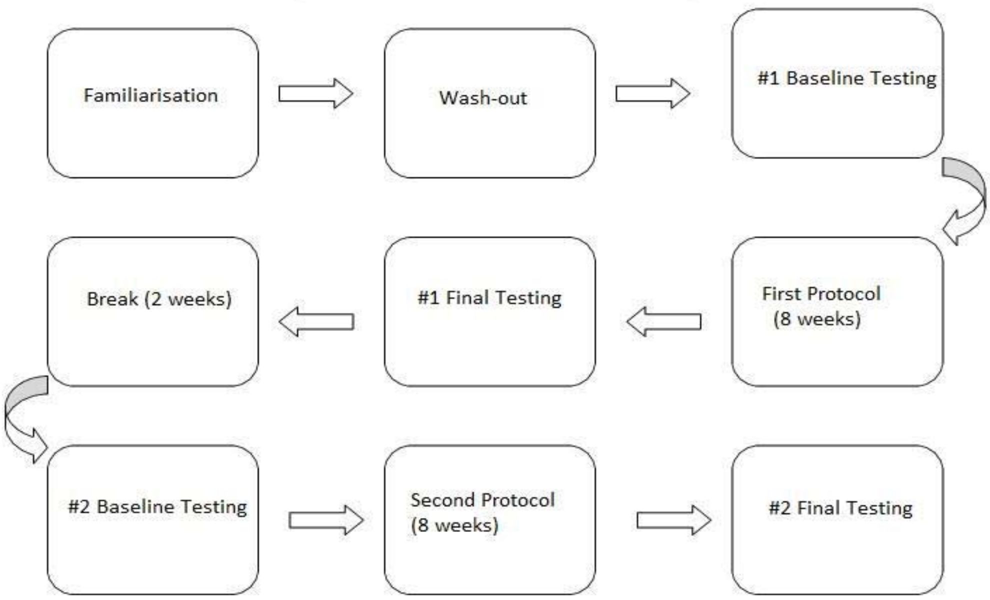

Figure 1. Flowchart Summarising Protocol Order. Each square represents one week of time unless stated.

Familiarisation Session

In week one you will be shown where 1RM testing will be carried out two weeks later. Details of training history will be recorded. You will be health screened, shown how to calculate AR training load, and given explanation of other protocol details for example how to put your training data online. You will also be informed of the criteria for a successful lift of the squat, bench press, and deadlift by which you have to following during baseline testing.

Wash Out Period

Week two has the goal of equalising your fatigue state so that you come into the baseline testing week fresh. During this week, continue your training as normal however reduce training load and volume by approximately 50%.

Baseline Measures

You will be required to establish a one-repetition-maximum (1RM) in the barbell squat, bench press, and dead lift. This will be carried out under supervision at the Practical Teaching Complex in the School of

Exercise Science at Massey University, Palmerston North. Three separate days will be scheduled within the same week for you to complete this (one exercise per day).

You will establish a 1RM following warm-up. The warm up will consist of a number of submaximal repetitions of the specific exercise that is to be tested. For example for the bench press: five repetitions of the bar only, three repetitions at a slightly heavier load, and two repetitions at a load heavier but still submaximal. A weight 50-70% of your perceived capacity will then be used for a single repetition. Load will then be adjusted upwards until a true 1RM (successful lift within the technique specifications for each lift) is found within three more trials. Three to five minutes rest will be given between attempts. Height will be taken during the initial baseline session, and bodyweight will be recorded during all 1RM testing days.

Criteria for a Successful Lift

The squat must be completed to a depth where the top of the patella is in line or below the hip crease and then the participant must stand up with knees and hips extended. The bench press requires lowering of the bar to the chest where it is paused for one second before being pressed back up and elbows extending fully at the top. The head, upper back, buttocks, and feet must remain in contact with the bench (or ground for the feet) at all times during the lift. In the deadlift the participant must stand up with the barbell to a fully erect posture without hitching the bar up the thighs. All lifts must be completed without any downwards movement during the concentric (upwards) phase of the lift.

Programme Outline

The study will be randomized and of cross-over design. Six participants will be assigned to each programme concurrently. The following outline is applicable to the training of the 3 main lifts completed under this protocol one time per week. Squats will be completed on Mondays, bench press on Wednesdays, and deadlifts on Fridays.

The traditional periodisation protocol will follow the schedule below:

Week 1: Familiarisation

Week 2: Wash out

Week 3: Baseline 1RM testing

Week 4: 1 set of AMRAP @ 85% 1RM then 2 sets x 10 reps @ 65% of 1RM

Week 5: 1 set of AMRAP @ 85% 1RM then 2 sets x 10 reps @ 72.5% of 1RM

Week 6: 1 set of AMRAP @ 85% 1RM then 3 sets x 6 reps @ 77.5% of 1RM

Week 7: 1 set of AMRAP @ 85% 1RM then 3 sets of 4 reps @ 82.5% of 1RM

Week 8: 1 set of AMRAP @ 85% 1RM then 4 sets of 3 reps @ 85% of 1RM

Week 9: 1 set of AMRAP @ 85% 1RM then 3 sets of 3 reps @ 87.5% of 1RM

Week 10: 1 set of AMRAP @ 85% 1RM then 4 sets of 2 reps @ 90% of 1RM

Week 11: 1 set of AMRAP @ 85% 1RM then 2 sets of 2 reps @ 95% of 1RM

Week 12: Post 1RM testing

Key: AMRAP – as many repetitions as possible

For AR training the same pre and post testing will be done and the same protocol will be followed (same number of sets and repetitions), as outlined above, however, training load will be modified daily depending on the number of repetitions completed in the first set (at 85% baseline 1RM), rather than using the 1RM measured at baseline.

The as many repetitions as possible (AMRAP) set prior to above percentage work will be utilised to calculate a 1RM in the AR group based on the following equations:

Bench press: Mayhew et al. (1992) equation: 100*weight/(52.2+41.9*exp[-0.055*reps]) = 1RM

Squat and deadlift: Wathen (1992) equation: 100*weight/(48.8+53.8*exp[-0.075*reps]) = 1RM

An excel chart of weights lifted for a given number of repetitions to predict 1RM, based on the previous two equations, will be provided for you to use during training.

Each protocol will require you to complete one AMRAP set, this will serve as the first working set so that this training stimulus is the same for each protocol and, in the case of AR, serve to determine the days training load. You will complete AMRAP with 85% and then, using the chart provided, workout their daily training load. In this way training load will be applied in an auto-regulated manner based on each day's fatigue/fitness level.

You will be given a two week break between protocols during which training load and volume will be reduced.

Table 1. *Assistance Exercises Prescribed Following Main Exercise*

Monday	Wednesday	Friday
Leg Press 3x6	Incline Barbell Bench Press 3x6	Pull-down 3x6
Leg Curl	Military Press	Barbell Row 3x6

3x12	3x6	
Crunch 3x12	Triceps Extension 3x12	Biceps Curl 3x12

These exercises will be completed in the first week with a weight which achieves within two repetitions or at fatigue on the last set. This weight will be static for the first four weeks of the programme and then increase 5% for the final part of the programme. Exercises involving smaller amounts of musculature have been prescribed at a lower intensity so that form can be maintained and larger muscle groups do not take control of the movement.

Training Diary & Participant Monitoring

You will be given a physical & online training diary within which you will record details such as number of repetitions obtained during the AMRAP sets, rating of perceived exertion using what scale through perceived repetitions left until failure, sets where you were unable to complete the prescribed repetitions, and additional information about other physical exercise you did in the week. You will input this during training sessions and then fill out the same diary online by the end of the week so it can be viewed. You will meet weekly with Mr Fraser to discuss your training diary and to ensure you are sticking to the protocol. One training session per week for each participant will be supervised by Mr Fraser within the Massey University Recreation Centre. The particular training session that this is will be alternated weekly ie Participant one will have their squat session monitored in week one and then their bench press session monitored in week two.

Diet Control

You will record your diet on the day of each 1RM testing (just what you eat/drink *prior* to testing on that day) and will be asked to replicate this for following testing days of the same exercise. For example, the diet consumed the day of baseline 1 squat test will match that of the diet consumed the day of final 1 squat test. Hand in the three pre-testing diets at the end of each testing period (for example on the deadlift testing day of baseline testing 1). No food will be consumed within two hours from testing. You will be asked refrain from stimulants (for example coffee) and alcohol 12 hours prior to testing. You are allowed to use pre-workout supplements prior to *training* (NOT testing) as long as between protocols this usage does not change. In addition, it is imperative that you do not attempt to significantly change your bodyweight (particularly through weight loss) through the course of this study.

Exclusion Criteria:

If any of the following apply:

- *You are not 18-45 years of age*
- *You are not interested in improving maximal strength*
- *You are involved in a competitive sport*
- *You are seeking to be involved in multiple studies concurrently*
- *You have not been participating in regular resistance exercise for the past two years*
- *You have not performed barbell squats, deadlifts, and flat bench press at least once per week for the past year*
- *You have a known heart or cardiovascular condition or if a member of your family died below the age of fifty (50) as a result of a heart condition.*
- *You have* ***any*** *current injuries which could be aggravated by performing a resistance training programme*
- *In the last six months you have suffered from any painful injury or condition that lasted more than one week*
- *You have had an injury or medical condition that you think may affect your ability to sense pain or discomfort*
- *You have ever had persistent or regular lower back pain.*
- *You are taking prescribed medication*
- *You have cultural or religious sensitivities about human body measurements*
- *You have any other reason to consider that you are not in good health and of average, or better than average, fitness*

.. you should **NOT** participate in this study.

Reimbursement:

You will be compensated $250 each to cover petrol costs to and potential extra training time to fulfil the requirements of this study. Should you withdraw at any stage during the study, you will be given a suitable proportion of the $250 based on how long you participated in the study.

Potential Risks:

As with any resistance training programme, there is a risk of musculoskeletal injury and/or discomfort during training or maximal testing. To minimise any risk you will be instructed on correct lifting technique during your familiarisation trial. The Massey University Recreation Centre is a commercial gym and so appropriate standard and first aid qualified staff are on hand.

If injury or illness occurs during the study to a degree that you miss one complete week of training, you may have to be removed from the study.

Data Management:

All participant data will be stored under password protection by the researchers and not shared with other participants or anybody outside of the research team. Following completion of the study, you may view your own data and anonymised pooled data.

Participant's Rights:

You are under no obligation to accept this invitation. If you decide to participate, you have the right to:

- Decline to answer any particular question;
- Withdraw from the study at any time;
- Ask any questions about the study at any time during participation;
- Provide information on the understanding that your name will not be used unless you give permission to the researcher;
- Be given access to a summary of the project findings when it is concluded.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 15/14. If you have any concerns about the conduct of this research, please contact Mr Jeremy Hubbard, Acting Chair, Massey University Human Ethics Committee: Southern A, telephone 04 801 5799 x 63487, email humanethicsoutha@massey.ac.nz.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

If your ACC claim is not accepted you should immediately contact the researcher. The researcher will initiate processes to ensure you receive compensation equivalent to that to which you would have been entitled had ACC accepted your claim.

Appendix B

Health Screening Questionnaire

A comparison between undulating periodization and load autoregulated periodization for maximal strength gain in the squat, bench press, and deadlift in weight-trained males
PRE-EXERCISE HEALTH SCREENING QUESTIONNAIRE

Name: ____________________

Address: ____

Phone: _______________________________

Age: ________________

Please read the following questions carefully. If you have any difficulty, please advise the researcher who is conducting the study. If you answered yes to any of the questions below more information may be requested to accurately assess your suitability to participate in this study.

This questionnaire has been designed to identify the small number of persons (15-69 years of age) for whom physical activity might be inappropriate. The questions are based upon the Physical Activity Readiness Questionnaire (PAR-Q), originally devised by the British Columbia Dept. of Health (Canada), as revised by [1]Thomas *et al.* (1992) and [2]Cardinal *et al.* (1996), and with added requirements of the Massey University Human Ethics Committee. The information provided by you on this form will be treated with the strictest confidentiality.

Please answer all of the following questions by circling only <u>one</u> answer for each question:

- ***Do you have a known heart or cardiovascular condition and/or has a member of your family died below the age of fifty (50) as a result of a heart condition?***

  Yes ***No***

- ***Do you have any current or previous injury that may be aggravated by strenuous exercise?***

  Yes ***No***

- ***In the last six months, have you suffered from any painful injury or condition that lasted more than one week?***

  Yes ***No***

- ***Have you had or do you have an injury or medical condition that you think may affect your ability to sense pain or discomfort?***

  Yes ***No***

- ***Have you ever had persistent or regular lower back pain?***

  Yes ***No***

- ***Are you taking prescribed medication?***

  Yes ***No***

- ***Have you been hospitalized recently?***

  Yes ***No***

- ***Do you have any other reason to consider that you are not in good health and of average, or better than average, fitness***

  Yes ***No***

You should be aware that even amongst healthy persons who undertake regular physical activity there is a risk of sudden death during exercise. Though extremely rare, such cases can occur in people with an undiagnosed heart condition. If you have any reason to suspect that you may have a heart condition that will put you at risk during exercise, you should seek advice from a medical practitioner before undertaking an exercise test.

I have read, understood, and completed this questionnaire.

Signature: ____

Date: _________________________

References

1. Thomas S, Reading J and Shephard RJ. Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Can J Sport Sci 17*(4): 338-345.

2. Cardinal BJ, Esters J and Cardinal MK. Evaluation of the revised physical activity readiness questionnaire in older adults. *Med Sci Sports Exerc 28*(4): 468-472

Appendix C

Training History Questionnaire

A comparison between undulating periodization and load autoregulated periodization for maximal strength gain in the squat, bench press, and deadlift in weight-trained males
TRAINING HISTORY QUESTIONNAIRE

Name: ____________________

1. Age (years): _________
2. Within the time period of the study, will you be partaking in other competitive sports?

Yes/No (circle one)

If yes, detail:

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3. When did you begin consistently weight training (2+times/week excluding holidays)?

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4. How long have you been consistently (1+ time/week);

   Barbell squatting:

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   Flat barbell bench pressing:

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Barbell deadlifting:

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Within the period of time you have been weight training, have you ever taken 1+ weeks off at any point?

Yes/No (circle one)

If yes, detail how long and when.

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Outline a typical week of training (include exercises, sets, reps, weights, rest periods, how many reps shy of failure, etc: as much detail as possible).

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Have you ever competed in a weight-lifting related sport?

Yes/No (circle one)

If yes, what and when?

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Appendix D

Consent Form

A comparison between undulating periodization and load autoregulated periodization for maximal strength gain in the squat, bench press, and deadlift in weight-trained males
CONSENT FORM

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I wish/do not wish to have my recordings returned to me.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name - printed ....

Appendix E

Training Diary

Participant	NAME							
#1 Baseline	**True Max**	**85% 1RM**						
Squat	NUMBER	#VALUE!						
Bench	NUMBER	#VALUE!						
Deadlift	NUMBER	#VALUE!						
Notes for participants								
Following warm up, complete a set at 85% of baseline 1RM for as many reps as possible (AMRAP)								
Use the provided table to work out the corresponding predicted 1RM from this.								
Then perform the prescribed percentage work based on the predicted 1RM.								
Auto-regulated programme								
Week 1 Day 1 (Monday)								
	AMRAP set (enter reps):	Predicted 1RM (enter weight from table)	Sets	Repetitions	Intensity (of predicted 1RM)	Weight	RPE (eg how many more reps could you have completed on the last set before failure?)	Additional Notes
Squat			2	10	65			
Pull-down			3	6	One or two reps shy of fatigue on last set			
Leg curl			3	12	One or two reps shy of fatigue on last set			
Crunch			3	12	One or two reps shy of fatigue on last set			
Week 1 Day 3 (Wednesday)								
	AMRAP set (enter reps):	Predicted 1RM (enter weight from table)	Sets	Repetitions	Intensity (of predicted 1RM)	Weight		
Bench press			2	10	65			
Military press			3	6	One or two reps shy of fatigue on last set			
Rear deltoid fly			3	12	One or two reps shy of fatigue on last set			
Bicep curl			3	12	One or two reps shy of fatigue on last set			
Week 1 Day 5 (Friday)								
	AMRAP set (enter reps):	Predicted 1RM (enter weight from table)	Sets	Repetitions	Intensity (of predicted 1RM)	Weight		
Deadlift			2	10	65			
Front squat			3	6	One or two reps shy of fatigue on last set			
Incline bench press			3	6	One or two reps shy of fatigue on last set			
Barbell Row			3	6	One or two reps shy of fatigue on last set			
Other Physical Activity Through the Week								
Detail any other physical activity you did this week and when.								
	Activity	**Duration**	**Intensity**					
Monday								
Tuesday								
Wednesday								
Thursday								

Appendix F

1RM Table Example (for squats and deadlifts)

Squat & Deadlift												
% of 1RM	100	97.5	92.5	90	87.5	85	82.5	80	77.5	75	70	67.5
Repetitions	1	2	3	4	5	6	7	8	9	10	11	12
Weight lifted (kg)	250	262.5	272.5	282.5	292.5	300	310	320	327.5	337.5	345	352.5
	247.5	260	270	280	287.5	297.5	307.5	315	325	332.5	342.5	350
	245	257.5	267.5	277.5	285	295	305	312.5	322.5	330	337.5	347.5
	242.5	255	265	272.5	282.5	292.5	300	310	317.5	327.5	335	342.5
	240	252.5	262.5	270	280	290	297.5	307.5	315	322.5	332.5	340
	237.5	250	260	267.5	277.5	285	295	302.5	312.5	320	327.5	335
	235	247.5	255	265	275	282.5	292.5	300	307.5	317.5	325	332.5
	232.5	245	252.5	262.5	270	280	287.5	297.5	305	312.5	320	330
	230	242.5	250	260	267.5	277.5	285	292.5	302.5	310	317.5	325
	227.5	240	247.5	257.5	265	275	282.5	290	297.5	307.5	315	322.5
	225	237.5	245	255	262.5	270	280	287.5	295	302.5	310	317.5
	222.5	235	242.5	250	260	267.5	275	285	292.5	300	307.5	315
	220	232.5	240	247.5	257.5	265	272.5	280	287.5	297.5	305	312.5
	217.5	227.5	237.5	245	252.5	262.5	270	277.5	285	292.5	300	307.5
	215	225	235	242.5	250	257.5	267.5	275	282.5	290	297.5	305
	212.5	222.5	232.5	240	247.5	255	262.5	272.5	280	287.5	292.5	300
	210	220	230	237.5	245	252.5	260	267.5	275	282.5	290	297.5
	207.5	217.5	225	235	242.5	250	257.5	265	272.5	280	287.5	292.5
	205	215	222.5	230	240	247.5	255	262.5	270	275	282.5	290
	202.5	212.5	220	227.5	235	242.5	250	257.5	265	272.5	280	287.5
	200	210	217.5	225	232.5	240	247.5	255	262.5	270	277.5	282.5
	197.5	207.5	215	222.5	230	237.5	245	252.5	260	265	272.5	280
	195	205	212.5	220	227.5	235	242.5	250	255	262.5	270	275
	192.5	202.5	210	217.5	225	232.5	240	245	252.5	260	265	272.5
	190	200	207.5	215	222.5	227.5	235	242.5	250	255	262.5	270
	187.5	197.5	205	212.5	217.5	225	232.5	240	245	252.5	260	265
	185	195	202.5	207.5	215	222.5	230	235	242.5	250	255	262.5
	182.5	192.5	200	205	212.5	220	227.5	232.5	240	245	252.5	257.5
	180	190	195	202.5	210	217.5	222.5	230	235	242.5	247.5	255
	177.5	187.5	192.5	200	207.5	212.5	220	227.5	232.5	240	245	250
	175	185	190	197.5	205	210	217.5	222.5	230	235	242.5	247.5
	172.5	182.5	187.5	195	200	207.5	215	220	227.5	232.5	237.5	245
	170	177.5	185	192.5	197.5	205	210	217.5	222.5	230	235	240
	167.5	175	182.5	190	195	202.5	207.5	215	220	225	232.5	237.5
	165	172.5	180	185	192.5	197.5	205	210	217.5	222.5	227.5	232.5
	162.5	170	177.5	182.5	190	195	202.5	207.5	212.5	220	225	230
	160	167.5	175	180	187.5	192.5	197.5	205	210	215	220	227.5
	157.5	165	172.5	177.5	182.5	190	195	200	207.5	212.5	217.5	222.5
	155	162.5	170	175	180	187.5	192.5	197.5	202.5	210	215	220
	152.5	160	165	172.5	177.5	182.5	190	195	200	205	210	215
	150	157.5	162.5	170	175	180	185	192.5	197.5	202.5	207.5	212.5
	147.5	155	160	167.5	172.5	177.5	182.5	187.5	192.5	200	205	207.5
	145	152.5	157.5	162.5	170	175	180	185	190	195	200	205
	142.5	150	155	160	165	172.5	177.5	182.5	187.5	192.5	197.5	202.5