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ESTABLISHING AN OPTIMAL RECOVERY TIME BETWEEN REPEATED MAXIMAL STRENGTH SETS ON THE SQUAT AND BENCH PRESS
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ABSTRACT
The purpose of the present research study was to identify and refine through testing the optimum recovery time between repeated maximal strength sets using the squat and bench press exercises. This study was conducted due to a paucity of data on the optimal inter-set rest duration in the strength and conditioning literature (Hill-Haas., 2007).

Seven male (n= 7) subjects from the University of Wales Institute Cardiff agreed to participate in the study (mean ± SD for age = 21.9 years ± 0.9, body mass = 93.2 kg ± 7.5). Subjects completed 4 repeated sets at their individual 4 RM load across 4 different interset recovery times, 30 seconds, 60 seconds, 90 seconds and 180 seconds. The total number of repetitions completed per set at each recovery period was recorded. Sustainability of repetitions was analysed across all recovery periods for both the squat and bench press.

The study concluded that a relationship existed between the number of repetitions completed at each rest interval on both the bench press and the squat (p<0.05). It was found that the shorter the rest interval between repeated maximal sets, the fewer the mean number of repetitions completed across all 7 subjects. The 180 second rest period between sets allowed for the most recovery and resultantly the highest number of successfully completed repetitions in both exercises. At the 30 second rest interval a statistical significant difference occurred (p=0.21) in the number of repetitions completed in the squat and bench press. The squat was found to be more sustainable across all rest periods than the bench press. The findings were consistent with previous research and the
lower sustainability of repetitions at the shorter recovery periods were attributed to the inability to sufficiently recover from both metabolic and neural fatigue. The findings are of use to strength and conditioning coaches and athletes, who are consistently seeking techniques to optimise adaptations and consequently strength performance. They are also of use to the general public who practice resistance training, they provide general guidelines of recovery for popular exercises.
CHAPTER ONE: INTRODUCTION

1.0 Introduction

Strength has been highlighted as the most important of all biomotor abilities for overall fitness and a prerequisite for the development of many other abilities such as speed, agility and power (Everett. 2007). Strength refers to the skeletal muscle’s ability to contract and exert a force against a resistance (Hazeldine, 1985). More recently strength has been defined by McArdle et al. (2006) as the maximum force, torque, or tension generated by any specific muscle or muscle group. There are many different types and methods of assessing strength.

Strength endurance can be described in both static and dynamic terms. Static strength is the ability to maintain a fixed joint position for a period of time. Whereas, dynamic strength refers to the muscles’ ability to resist fatigue and continually contract in order to sustain a maximal or sub-maximal force for duration of time (Everett. 2007). Maximal strength refers to the muscles ability to overcome maximal resistance, such as a one rep maximum. Absolute strength has been defined by Clegg (1995) as the capacity to produce a large overall force measured in absolute terms kilograms (kg) or Newtons (N). True absolute strength would only be possible in the absence of protective and inhibitory mechanisms, thus is gauged more as an estimated potential quotient (Everett. 2007). Alternatively strength can be expressed as relative, where the maximal force production is related to the body mass, load divided by the body mass, to give a relative value which is a more accurate and fair reflection of strength.

Strength is transferable and maximal strength is at the core of strength
development, any increases in maximal strength will transfer to some degree to all types of strength (Everett. 2007). According to McArdle et al. (2006) the most commonly used methods to assess muscular strength are; cable tensiometry, dynamometry, one-repetition maximum (1-RM) and computer-assisted electromechanical and isokinetic determinations.

Strength training has increased markedly in popularity over the last decade and not only amongst the athletic population looking to further enhance performance but also in the general public with individuals looking to improve their physique (Hannie et al., 1995). A large proportion of the active population engage in resistance training as part of their job, their profession, for recreational purposes, rehabilitative reasons and many others (Willardson & Burkett, 2006a). Power underpins successful performance in numerous athletic activities, thus training protocols that optimize strength are of significant value to strength and conditioning coaches and athletes (Lawton et al., 2006). In some sports such as weightlifting strength is virtually the sole determinant of performance. In other sports such as rugby and American football strength is a key determinant but must be coupled with other abilities. Strength training now forms part of most athlete’s training programmes regardless of the sport, the specific sport will inevitably control the intensity and frequency of strength training with regard to how critical it is to performance. For these specific and general reasons it is important to know how to optimize strength gains.
Resistance training programmes are usually designed to stimulate improvements in muscular strength, muscular power, muscular hypertrophy or muscular endurance (Willardson & Burkett, 2006b). Manipulation of specific training variables determines the degree to which these characteristics of strength are increased and the manipulation is dictated by the goal orientation of the individual (Willardson & Burkett, 2006a). The key training variables according to Willardson and Burkett (2006b) are mode of exercise, intensity, volume, frequency, repetition velocity and rest period between sets. Effective strength training utilizes the training variables and principles of training to optimize the stress on the muscle in order to achieve the desired response. The principle of specificity, as noted by Willardson and Burkett (2006b), dictates that the type of muscular adaptation is a direct result of the specific training stimulus applied. Specificity combines with the principle of overload which reflects the percentage of maximum strength a pre-fatigued muscle can exert relative to the 1-RM. Muscular overload is often referred to as training intensity and is quantified as a percentage of the 1-RM and represents the most important principle in determining strength development (McArdle et al., 2006). General muscular strength training requires a load between 85%-100% of the 1 RM typically for between 1 and 6 reps of 1-4 ‘working’ sets (excluding warm up sets) depending on the individual, level and sustainability of the event (Bompa, 1999).
A key and generally overlooked area of focus when designing a proper resistance program is rest duration between sets (Richmond & Goddard, 2004). Recovery is not only essential between sets of performance but also over the entire routine. It is directly related to intensity and volume and must be prescribed accordingly (Everett, 2007). Jeffreys (2005) states that when designing any program it must be understood that only when athletes are able to optimally balance training intensity and subsequent recovery that optimal performance can be achieved. Recovery must be proactive and an integral part of the training program. Recovery has been defined by Jeffrey’s (2005) as an;

“inter-and intra-individual multilevel process in time for the re-establishment of performance abilities”

Optimal rest strategies are dependent upon the individual and the nature of the training, and are influenced by the type of fatigue, current training and non-training levels of stress and their ability to cope with the stressors. Fatigue has been evaluated as a complex phenomenon and a result of both central and peripheral factors (Meeusen et al., 2006). Sale (2002) states that at any point in time the skeletal muscle’s ability to perform is affected by its contractile history and the obvious effect of contractile history is fatigue which inhibits performance. Fatigue can be described as an exercise-induced reduction in maximal force generating capacity and recovery from fatigue involves two stages (Jeffreys, 2005). Short-term recovery involves the re-establishment of performance
parameters such as phosphocreatine (PC) and glycogen stores which takes place during the recovery time between sets, highlighting the importance of inter-set recovery duration. Long-term recovery relates to neural and metabolic processes that take longer to rejuvenate and most importantly the development of the athlete’s tolerance to physiological, psychological and emotional stressors (Jeffreys, 2005). In order to achieve optimal recovery the process needs to encompass techniques specifically tailored to the individual and the goal orientation and systematically integrate them into the training program. If the recovery process is inadequate and muscles are not fully recovered they are unable to maintain training intensity and strength gains are hindered. Continued insufficient recovery can lead to exhaustion and ultimately overtraining.

Resistance training programmes are designed to stimulate improvements which are the result of underlying adaptations. An adaptation is referred to as the way in which the body adjusts to a repeated stimulus (McArdle et al., 2006). Adaptations can occur in both the nervous system and the muscular system. Neural adaptations include increased central nervous system activation, lowered inhibitory reflexes and improved motor unit recruitment and synchronization. Muscular adaptations encompass both structural changes to the musculature and metabolic and cellular adaptations. Adaptations include increased myofibril size, increased amounts of contractile proteins, increased strength of connective tissue, increased intramuscular fuel stores, increased bone mineral content and increased enzyme concentrations (Bompa. 1999).
As stated by Hill-Haas (2007) there is paucity of data on the optimal inter-set rest duration. Therefore the purpose of the investigation is to identify and refine through testing the optimum recovery time between repeated maximal strength sets using the squat and bench press exercises. The squat and bench press exercises have been selected due to their popularity in resistance training programmes and the fact that they are primary exercises used to evaluate strength globally (Ware et al., 1995). Furthermore it aims to establish any relationships between the musculature of the upper and lower body with regard to recovery duration and performance parameters. The findings of the investigation aim to provide further insight into the most effective methods of improving strength gains through strength and conditioning training.
CHAPTER TWO: LITERATURE REVIEW

2.1 Resistance Training Variables

In order for training to be effective, key variables must be incorporated into a structured series of individual routines which are systematically varied intentionally and specifically in order to accomplish periodic goals and address areas of interest, commonly known as a training programme (Everett. 2007). Manipulation of acute training variables such as exercise sequence, exercises and sessions, rest period between sets, training frequency, velocity of movement, training volume and duration, number of repetitions and sets and intensity will impact on the success of the programme (Miranda et al., 2007). According to (Everett. 2007) the 2 most important training variables which are interdependent are technique and intensity. Technique has been identified as the most influential variable and can determine the success or failure of an entire programme (Everett. 2007). The nature of the relationships is that certain techniques will limit or support the level of intensity that can be applied and likewise the intensity will impact on the ability to maintain correct technique. Therefore, intensity must be applied appropriately to the desired exercise and technique (Everett. 2007).

González-Badillo et al (2006) recognise intensity as the most influential training variable when constructing a training programme for elite strength performers. Intensity is gauged as the amount of effort applied in relation to maximal effort possible, average relative intensity is expressed as a percentage of the 1RM
which represents the absolute kilograms lifted divided by the number of repetitions performed at the load (González-Badillo et al., 2006). Intensity is closely related to the training principle of progressive overload, which concludes that sufficient intensity and duration must be placed upon the muscles in order to overload them and stimulate adaptation and thus the intensity affects the type and level of adaptation.

2.1.1 Intensity, Duration and Frequency

Research has established that repeated exposure to weight-bearing exercise has a positive and often dramatic effect on muscle strength and mass (Candow & Burke 2007). However, the frequency with which to perform weight training in order to achieve optimal muscle strength and mass, and its relationship with intensity and volume provides controversy (Candow & Burke 2007). Findings have come to recommend that an inverse relationship between intensity on one side and duration and frequency on the other (Everett. 2007). The time it takes to complete a set is inversely affected by the intensity of the work, the greater the load the shorter the time the muscle is under tension as the muscle is being overloaded. The overall duration of the routine in its entirety is a result of the total volume of all the exercises. Frequency also needs to be planned relative to intensity. However, this can impact on other dimensions of a programme thus many athletes, especially bodybuilders who desire maximum hypertrophic gains, will detail sessions specific to a single or pair of muscle groups. This method reduces the frequency of the stimulus to each body part, effectively allowing
sufficient recovery relative to the high intensity and volume, without altering the frequency of the actual training (Candow & Burke 2007).

Candow & Burke (2007) conducted a study to determine the effect of short-term equal volume resistance training with varying frequency on muscle strength and lean tissue mass. Male and female subjects were assigned to 2 groups, one training twice per week and one training three times per week. Lean tissue mass and 1 RM bench press and squat were recorded pre and post study to observe and validate changes. The results showed an increase in lean body mass of 2.2% for both groups and increases in bench press strength (22-30%) and squat strength (28%). The results showed no difference between muscle accretion and strength gains on an equal volume training programme, suggesting training volume may be more influential than frequency at increasing muscle mass and strength.

Table 1 below illustrates the intensity-volume relationship and shows all the volume components that can be attuned with regard to increasing intensity. As the training intensity increases from muscular endurance to strength the number of repetitions decreases as does the volume. The tempo is increased, the time the muscle is under tension is increased and resultantly the longer the rest periods between sets allowing for sufficient recovery.
### Table 1: Intensity and Volume Relationships (Everet. 2007)

<table>
<thead>
<tr>
<th>Training Goals</th>
<th>Intensity</th>
<th>Repetitions</th>
<th>Set</th>
<th>Sub-Total (1)</th>
<th>Tempo Assignment</th>
<th>Sub-Total (2) (s)</th>
<th>Exercise/Muscle Group</th>
<th>Initial Volume (s)</th>
<th>Inter-Set Rest (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endurance</td>
<td>X</td>
<td>17</td>
<td>2</td>
<td>34 reps</td>
<td>2111 (5 sec)</td>
<td>170 sec</td>
<td>3</td>
<td>510 sec</td>
<td>30-60 sec</td>
</tr>
<tr>
<td>Hypertrophy</td>
<td>x+y</td>
<td>10</td>
<td>3</td>
<td>30 reps</td>
<td>3121 (7 sec)</td>
<td>210 sec</td>
<td>2</td>
<td>420 sec</td>
<td>60-240 sec</td>
</tr>
<tr>
<td>Strength</td>
<td>x+y+z</td>
<td>5</td>
<td>5</td>
<td>25 reps</td>
<td>4122 (9 sec)</td>
<td>225 sec</td>
<td>1</td>
<td>225 sec</td>
<td>300+ sec</td>
</tr>
</tbody>
</table>

#### 2.1.2 Intensity and Recovery

During high intensity resistance training the body’s systems are placed under extreme stress. The passive and active joint and tissue systems along with the neural system experience high levels of stress and fatigue. It has been found that the body takes longer to recover from neural fatigue than metabolic fatigue (Everett. 2007). Traditionally passive recovery between sets is undertaken when strength training, however, more recently active recovery has been introduced. For example, performing movement patterns which are unrelated or opposite to those previously executed and activate different muscle groups to those previously activated are known as supersets. Supersets of this nature enable increased recovery duration for the previously activated muscle and provide an opportunity for an increased volume of work to be performed (Everett. 2007).
2.1.3 Intensity and Sequence

Exercise order refers to the sequence of exercises in a given training session (Simão et al., 2005). The required intensity level of a particular exercise will dictate its order in the sequence of the training routine. Spreuwenberg et al., (2006) recognised that the order of the exercise in the sequence can have dramatic impact on quality (technique and intensity) of the constituent exercises. Previous research into exercise order in relation to performance such as that conducted by Sforzo and Touey (1996) found that when exercises such as the leg extension and arm extension were performed prior to the squat and bench press a decline in performance of 75% and 22% respectively were observed. The study conducted by Spreuwenberg et al., (2006) looked at the back squat (4 sets at 85% 1RM) when performed first in one protocol (protocol A) and following a whole body workout in the other protocol (protocol B). Performance was gauged using 3 assessment parameters including average power output, repetitions and rate of perceived exertion (RPE). Findings indicated a significant increase in the number of repetitions performed by all subjects following protocol A. However, average power output data was higher following protocol B than for protocol A and RPE values showed no significant difference.

Simão et al. (2005) recommend that exercises that involve large muscle groups should be completed at the onset of the training session based on the fact that using the heaviest resistance on the largest muscle groups results in the greatest long term strength gains. It has also been proposed that the sequence should
allow for the training resistances and volumes that optimise adaptations (Simão et al., 2005). The study conducted by Simão et al. (2005) used 2 groups completing upper-body exercises only, one of which completed large muscle group exercises first, progressing to smaller muscle group exercises, and the other group did the opposite. The key findings of the study were that the sequence of exercises in an upper-body only session does affect the number of repetitions completed in both small and large muscle groups. The other key finding was that when exercises were performed last in the training programme, the number of repetitions to volitional fatigue is reduced (Simão et al., 2005).

2.1.4 Volume

Coaches and researchers continually attempt to identify the most effective relationship between the numerous indicies of training (González-Badillo et al., 2006). González-Badillo et al. (2006) state that in order to improve strength performance it is essential to systematically increase the stress-related overload on the muscle. This can be achieved by manipulating volume, which is the total amount of time a muscle is under tension. Volume can be split into two constituents, initial volume (IV) and total volume. Initial volume is a measure of the total duration of time that a specific muscle is under tension in a routine and is calculated by multiplying the number of reps by the number of sets and then multiplying again by the duration it takes to complete each rep (tempo). If the routine is divided into body parts then the number of exercises that target the specific muscle also need to be accounted for (IV=reps x sets x tempo x exercises per muscle group) (Everett, 2007). Total volume is then calculated by
multiplying the initial volume of each routine by the frequency to which it is carried out in the given training cycle.

González-Badillo et al. (2006) investigated the effect of 3 volumes of heavy resistance, average relative intensity, on maximal strength in various weightlifting movements over a short-term 10 week period. The study concluded that during a short-term resistance training programme using moderate volumes of high relative intensity, greater enhancements in weightlifting performance were produced in comparison to low and high volumes of high relative intensity. This suggests that increasing training intensity may not always provide a more effective stimulus for enhancing adaptations (González-Badillo et al., 2006). The study also interestingly suggests that when a threshold level of strength has been reached, physiological adaptations may be at their optimum and that further increases in training intensity may provide no further enhancements (González-Badillo et al., 2006).

With regard to volume, the number of sets performed during weight training exercises has an impact on strength development. Previous research has shown that multiple sets produce greater strength gains than single sets (Rhea et al., 2002). Rhea et al. (2002) identifies the need to determine the dose response relationship between volume and strength gains, thus if 1 set elicits greater or equal gains to 3 sets there is no logic in performing the latter. The investigation carried out by Rhea et al. (2002) examined the effects of a single set training
protocol and a triple set training protocol with equal intensity and frequency on 1 RM bench and leg press strength. Results indicated that performing 3 sets elicits greater strength gains (30% and 13% in the leg press and bench press respectively) than performing a single set.

2.2 The Bench Press

As resistance training becomes an increasingly popular method of enhancing physical fitness there is an increased demand for primary exercises to evaluate strength in specific muscle groups (Cotterman et al., 2005). The bench press alongside the squat is recognised as one of the most common and frequently used core exercises in resistance training programmes (Ware et al., 1995) and is a competitive movement in its own right (Tod et al., 2005). Maximal dynamic strength is commonly measured and referred to as the 1 RM and is widely recognised as the reference standard for the evaluation of strength (Kim et al., 2002). The technique requires the muscle or muscle group to successfully lift the heaviest load possible once, whilst maintaining correct technique and moving the load through a full range of motion (ROM) (Kim et al., 2002). In the case of the bench press the muscles of the chest, the pectoralis major, pectoralis minor and the anterior deltoid. The standard method for calculating the 1 RM is described by Matuszak et al. (2003) as a series of single repetitions completed with a progressively heavier load until the lift can no longer be completed. The bench press is described as a free form and free weight exercise in that the bar is not externally controlled and the movement takes place and requires balance in multiple planes (Cotterman et al., 2005). The 1 RM protocol is flawed in
numerous ways. Attempting a maximal lift requires high levels of concentration and mental preparation (Ware et al., 1995) and apprehension is often experienced by individuals, particularly in those that are untrained and as a result underestimation of their actual strength occurs and the performance is compromised (Kim et al., 2002). It is also a time consuming and fatiguing protocol and multiple maximal repetitions completed preceding the actual 1 RM load result in fatigue and thus may affect the established load (Matuszak et al., 2003). Furthermore, the 1 RM presents injury concerns and although the incidence of injuries is low amongst experienced weight trainers, untrained exercisers are more susceptible to injury when unaccustomed to handling heavy loads (Kim et al., 2002). Maximal free weight exercises also require multiple personnel for safety purposes to ‘spot’ the individual in the event of a loss of control.

As a result of the above, studies such as that completed by Kim et al. (2002) testing alternative methods of assessing maximal strength have been conducted. Kim et al. (2002) tested the hypothesis that the YMCA bench press test, which involves pressing a fixed weight at a fixed cadence of 30 repetitions per minute, was a valid predictor of 1 RM. The study concluded that the YMCA bench press test was a valid estimation in men ($r^2 = 0.884$) and women ($r^2 = 0.816$). Furthermore, the increased popularity in maximal testing has resulted in the production of exercise equipment to train and test on (Cotterman et al., 2005). Machine weight modes are described as fixed-form exercises where a movement
pattern is fixed and maintained through the range of motion (Cotterman et al., 2005). Such substitutions are used based on the ability of the lifter and testing requirements. The most commonly used machine is the multi-purpose Smith Machine which uses an Olympic sized bar which is attached on both ends with linear bearings to a vertical pole that the bar moves up and down acting as a guide rod (Cotterman et al., 2005). The frame of the machine contains safety hooks every few inches and the bar contains a latch on each end which with a slight rotation of the wrist will latch onto the hook and lockout to prevent further motion of the bar. The vertical motion of the bar remains on a fixed path and the decreased need to balance the weight and bar increases the safety of using this mode of training (Cotterman et al., 2005). For this reason and psychological comfort of the performer the Smith machine was used in the current study.

2.3 The Squat

Abelbeck (2002) recognises the squat as one of the most widely used leg exercises for enhancing strength and power. A number of variations of the squat have been developed to evaluate functional capacity and back stress due to the fundamental nature of the movement (Abelbeck, 2002). The squat predominantly assesses the strength of the leg musculature through a full repetition. A repetition constitutes a full eccentric (plyometric/lengthening) action, for example in the squat performed by the muscles of the hamstring (biceps femoris, semitendinosus and semimembranosus), followed by a full concentric (miometric/shortening) action, performed by the quadriceps (the vastus medialis, vastus intermedius, vastus lateralis and the rectus femoris), through the
maximum range of movement about a joint arc (ROM) (McArdle et al., 2006). As with the bench press alternative exercise devices have been used such as the Smith machine. Specific to the squat a hack squat machine has been developed which places the individual in a semi-reclined position to provide support of the pelvis and lower back (Abelbeck. 2002). Such devices remove the necessity for balance of the external load as the machine has only a single degree of freedom. It is noted by Cotterman et al. (2005) that the fixed motion of the bar on a Smith machine may induce alterations in technique, muscle recruitment and force production compared to the free-weight equivalent. Abelbeck (2002) identified that linear track machines create variation in anterior-posterior foot placement causing horizontal forces to be applied to the floor and the machine and that theses forces have the potential to significantly alter the loads placed on the body. Figure 1 shows a free body diagram of the linear motion squat.
The study conducted by Abelbeck (2002) looking at changes in knee and hip moments as a result of varying foot position in a linear motion squat found that foot positioning is a crucial factor affecting the moments generated and therefore the specific muscle groups stressed. The study by Cotterman et al. (2005) comparing muscle force production using the Smith machine and free-weights for the squat and bench press produced interesting findings. The squat 1 RM was greater on the Smith machine than on the free-bar but the bench press was greater on the free-bar than on the Smith machine.
2.4 Hormonal Responses to Resistance Training

It is understood that systemic strength training has a potent effect on inducing gains in skeletal muscle mass and strength (Ahtiainen et al., 2005). Ahtiainen et al. (2005) attributes the adaptations to a combination of mechanical stress, metabolic demands, neuromotor control and endocrine activities. Heavy resistance training is a potent stimulus for muscle cell hypertrophy and according to Kraemer et al. (1990) this may be due to an exercise induced increase in endogenous growth factors and anabolic hormones such as growth hormone (GH) and testosterone (T). Linnamo et al. (2005) state that heavy resistance exercise leads to acute increases in serum GH and T concentrations and Kraemer et al. (1990) suggest that resting values of testosterone may be elevated as a result. Ahtiainen et al. (2005) and Linnamo et al. (2005) associate acute increases in growth factors and hormones with acute decreases in neuromuscular function. Acute decreases in neuromuscular function result in decreased maximal force production and thus inhibit further contractions (Ahtiainen et al., 2005). However, the acute anabolic hormone increase of GH and T have been linked to increased levels of protein synthesis in skeletal muscle cells and may be a key trigger to the adaptive process of skeletal muscle leading to an increased level of contractile proteins such as actin and myosin (Ahtiainen et al., 2005). Kraemer et al. (1990) investigated the acute endocrine response to heavy resistance training using a 10 RM with 2 recovery periods, 1 minute and 3 minutes. The investigation revealed markedly higher hormonal responses with the shorter rest period. Linnamo et al. (2005) propose that
increased GH levels are in part a response to acidosis resulting from increased lactate production during such exercise. The induced hormone response varies depending on the intensity, rest period, volume and muscle mass invoked in the exercise according to Ahtiainen et al. (2005).

2. 5 Responses and Adaptations To Resistance Training

Resistance programmes can be generally categorized as either 'hypertrophy type' or 'strength type', with the former utilising moderate to high intensity exercise with more repetitions and shorter recovery durations. The latter uses high intensity exercise with fewer repetitions and longer recovery durations (Goto et al., 2004). Seynnes et al. (2007) states that resistance training induces muscular and neural adaptations. Mechanisms underlying the difference in effect include metabolic, mechanical and neural factors and influence the adaptations acquired. Most regimes therefore incorporate both strength and hypertrophic phases. The general consensus is that the initial strength gain is attributed to neural intervention and there is a slight delay before muscle hypertrophy is experienced (Seynnes et al., 2007). The neuromuscular system provides numerous mechanisms through which force output can be affected, including excitatory drive to lower motor neurones, motor neurone excitability, sarcolemma excitability, excitation contraction coupling, neuromuscular transmission and contractile mechanisms (Clark et al., 2006). Increases in neural drive have been reported within weeks of strength training. Seynnes et al. (2007) conducted a study into changes in muscle size and architecture over a 35 day high resistance training programme. Cross-sectional area of the quadriceps, maximal voluntary
contraction and electromyographic activity were used to gauge changes. The findings demonstrated a 38% increase in muscle strength in the quadriceps with only a 6.1% ± 1.1% increase in cross-sectional area (CSA). This suggests that the bulk of the strength gain was a result of neural factors. Muscle architectural changes were also observed with a 2% increase in fascicle length and pennation angle suggesting the addition of sarcomeres which is effectively muscle growth and enables more forceful contractions (Seynnes et al., 2007). It has also been noted that cellular and molecular responses that induce muscle growth, such as gene transcription factors, local production of insulin-like growth factor I (IGF-1) and protein synthesis rate are stimulated almost immediately following a single bout of resistance exercise. As previously mentioned the exercise induced influence of anabolic hormones is thought to facilitate protein synthesis and thus increase muscle hypertrophy (Goto et al., 2004).

Rhea et al. (2002) regard the rest interval between sets to be of paramount importance when striving to achieve overload. A theory known as the Corridor Theory has been proposed by Zatiorisky. The theory states that the only motor units that will experience adaptation are those which are both recruited and exhausted. Repeated recruitment and exhaustion of the motor units over time will result in maximum increases in strength. However, if too much recovery time is provided the previously recruited motor units may recover and subsequently be recruited again in the following sets. Therefore training the same set of motor units over and over. If however, recovery time is insufficient then a new set of
motor units will be recruited and overloaded in the next set. This scenario overloads multiple sets of motor units and therefore can overload more muscle fibres resulting in increased strength gains (Zatiorsky, 1995).

2.6 Fatigue

Fatigue has been defined by Meeusen et al (2006) as an exercise induced decline in the muscles capacity to exert force. Fatigue manifests itself in two ways, through central fatigue and peripheral fatigue, which mutually influence one another and a combination of the two resultantly lead to decreased performance (Meeusen et al., 2006). According to Babault et al. (2006) central fatigue arises proximal to motor axons and is responsible for reductions in motor unit activation, consequently hindering muscle recruitment and force production. Peripheral fatigue arises within the muscle and is associated with alterations at the neuromuscular junction or terminal branches of the motor axons (Babault et al., 2006).

Babault et al. (2006) conducted an investigation into neuromuscular fatigue development during maximal concentric and isometric knee extensions. Nine active males performed two separate fatiguing sessions, session one comprised 30 maximal voluntary concentric knee extensions and session two involved 3 long lasting isometric contractions that mimicked the torque decreases recorded in the concentric session. Maximal voluntary torque, activation level, electromyography of the vastus lateralis and mechanical properties were recorded pre and post training. The study revealed differing fatigue profiles when
performing the different types of muscle contraction. Peripheral fatigue was formerly observed with central fatigue following in the concentric sessions, whereas the opposite was experienced with the isometric session, where central fatigue was stimulated firstly followed by peripheral fatigue. A limitation to the study is that it examines only the two types of muscle contraction on the vastus lateralis and with inter-muscle and individual variability in muscle composition the findings cannot be applied to muscles of the chest for example.

According to Hannie et al. (1995) muscle fatigue is a direct result of intensity and duration. On a metabolic level fatigue has been attributed to increased acidity caused by an increase in hydrogen ion accumulation in the muscle. This reduced pH is responsible for reduced enzyme activity (ATPase and creatine kinase) responsible for energy transfer (Hannie et al., 1995). Lactate and the accumulation of hydrogen ions are linked to intense resistance exercise and are dependent on the intensity and duration of exercise.

2.7 Recovery Literature
According to Miranda et al. (2007) careful manipulation of rest period duration is a crucial factor when designing an effective resistance training programme and one which is frequently overlooked. Fatigue and recovery are time dependant process that encompass both metabolic and non-metabolic factors and can be split into short and long term phases (Woods et al., 2004). Short term recovery includes the re-establishment of performance capabilities whereas long term recovery serves to increase tolerance to stress through adaptations (Jeffreys.
According to Jeffreys et al. (2005) the main functions of the recovery period are: normalization of functions, normalization of homeostatic equilibrium, replenishment and temporary supercompensation of energy resources and reconstructive functions, particularly cellular processes and enzymatic functions. A number of studies have concluded that short rest intervals between sets do not allow sufficient time for muscle recovery thus having a detrimental effect on subsequent exercise (Woods et al., 2004).

Several studies have sought to establish ideal interest rest periods to maximise force production (Woods et al., 2004). According to Richmond and Goddard (2004) the body requires rest to allow the muscles to recover and restore their enzymatic capacity to exert force. Matuszak et al. (2003) found that a 1 RM back squat was repeatable with a 1, 3, 5 and 10 minute rest period between sets. However, the results are only applicable to strength testing as only 2 sets were performed, whereas in resistance training programmes a higher volume of exercise is performed. Willardson and Burkett (2005) sampled recreationally trained men to determine the effect of 1, 2 and 5 minute interset rest intervals on 4 repeated sets of 8 RM bench press and squat exercises. The 5 minute rest period allowed for the greatest number of repetitions to be completed, followed by the 2 minute and finally 1 minute rest interval. However, in the squat there was no significant difference in the number of repetitions completed between the 1 and 2 minute rest intervals. The bench press demonstrated significant differences across all 3 rest intervals in the total number of repetitions completed.
This investigation suggests that there may be inter-muscle variability with regard to recovery ability. Richmond and Goddard (2004) investigated the number of bench press repetitions completed in 2 concentric sets to failure at 75% of their 1 RM using interset rest intervals of 1, 3 and 5 minutes over an 8 week training period. The data proposed that subjects were unable to optimally recover between the first and second sets at any of the rest intervals. There was no significant difference in work performed between the 3 and 5 minute recovery periods, however, the work performed at the 1 minute rest interval was significantly less than both the 3 and 5 minute periods.

An alternative method to performing a number of fatiguing continuous repetitions is to introduce a rest interval after each repetition, an interrepetition rest period (Lawton et al., 2006). Lawton et al. (2006) aimed to assess the impact of interrepetition rest intervals on weight training power output using elite basketball and soccer players. The subjects performed 6 RM on the bench press at 3 different interventions. The interventions were as follows; singles, 6 x 1 repetition with 20 seconds rest between each repetition, doubles, 3 x 2 repetitions with 50 seconds between each pair of repetitions and triples, 2 x 3 repetitions with 100 seconds rest between each 3 repetitions. Greater power outputs (25-49%) were observed in the singles, doubles and triples in the latter repetitions, 4-6. Significantly greater total power outputs were experienced over all of the interrepetition rest intervals in comparison to the traditional continuous 6 RM power output. In conclusion the investigation found that using an interrepetition
rest interval allows increased repetition and total power output when compared to standard loading parameters (Lawton *et al.*, 2006). Further investigation is needed into different athletic populations, especially those that require greater upper body power. It has been noted by Lawton *et al.* (2006) that this method of loading may serve to increase strength through enhanced neural adaptation as a result of the shorter time the muscle is under tension.

### 2.8 Rationale

As stated by Matuszak *et al.* (2003) a detailed understanding of the responses to rest intervals associated with repeated maximal exercise is of value to strength and conditioning professionals and athletes in order that training can be accurately prescribed to optimize performance. Therefore the purpose of the current study is to evaluate the effects of differing interset rest intervals on the reproducibility of maximal efforts in the squat and bench press, with the intent of establishing an optimal recovery time. In addition a lower body and upper body exercise have been selected for testing to determine whether there is intra-muscle variability in optimal recovery times for strength exercises, particularly between upper and lower body muscles and thus to determine if the results of the study can be applied to a broader range of strength training exercises. The study follows a 4 set 4 RM protocol to failure with 4 differing recovery periods of 30 seconds, 60 seconds, 90 seconds and 180 seconds. This combination of recovery times using 4 sets at 4 RM have not previously been investigated. For the purpose of the current investigation optimal recovery is defined as the ability to complete 16 repetitions (4 x 4) at the selected rest interval.
2. 9 Hypotheses

It can be hypothesised that the 180 second rest interval will enable the greatest number of repetitions to be completed in accordance with previous research (Matuszak et al., 2003; Richmond & Goddard 2004; Willardson & Burkett, 2005; Willardson & Burkett, 2006a; Hill-Hass et al., 2007).

It can also be hypothesised that the squat will recover more effectively at each recovery period than the bench press, evidenced by the number of repetitions completed.

The null-hypothesis states that there will be no difference in the number of repetitions completed across the 4 rest periods for both the squat and bench press.
CHAPTER THREE: METHODOLOGY

3.0 Experimental Approach to the Problem

To examine the effects of four differing interset recovery intervals, 30 seconds, 60 seconds, 90 seconds and 180 seconds on 4 repeated sets at 4 RM on squat and bench press performance with the view to establishing an optimal recovery time.

3.1 Subjects

Seven male (n= 7) students from the University of Wales Institute Cardiff agreed to participate in the study (mean ± SD for age = 21.9 years ± 0.9, body mass = 93.2 kg ± 7.5). Subjects were required to have at least 6 months resistance training experience due to the maximal nature of testing. Participants were required to be in good health and free from injury and illness in order to participate in the study. Health status of participants was ascertained through the completion of a Physical Activity Readiness Questionnaire (PARQ) (Woods et al., 2004; Willardson & Burkett 2006a; Miranda et al., 2007) (Appendix A). Participants were also required to complete an informed consent form prior to their involvement in the study in accordance with human subject regulations (Matuszak et al., 2003; Richmond & Goddard 2004; Woods et al., 2004; Willardson & Burkett 2006a) (Appendix B) and made aware they have the right to withdraw from the investigation at any time if they wish to and their names would remain confidential. Subjects were permitted to continue with their individual training routine around testing with the following exceptions; 1) Subjects were asked not to perform leg or chest workouts within 24 hours prior to testing and 2)
subjects were asked not to take part in training prior to or after testing (Willardson & Burkett 2006a). Creatine supplementation was prohibited and subjects reporting use during the time of the study were not eligible and excluded (Rhea et al., 2002). The use of sports beverages and food consumption during training was also prohibited.

3. 2 Initial Testing
An initial meeting was held with the eligible participants in order to record their descriptive characteristics such as age and weight. The protocol used to establish the 4 RM was also described to each subject. The protocol for establishing the 4 RM was a manipulation of the reference standard protocol used by Matuszak et al. (2003) to determine 1 RM. A series of four repetitions completed with a progressively heavier load until the subject can no longer lift complete 4 repetitions, this load was their 4 RM. This method was adopted as opposed to using methods which derive 4 RM values from a 1 RM as it enables subjects to familiarise themselves with the equipment and provides a practical representation and replication of the multiple set testing protocol. Subjects were then asked to calculate their individual 4 RM in their own time so as not to place excessive time constraints on them. Individual 4 RM data can be seen in appendix 1. Following this the four recovery intervals were randomized so as to eradicate ‘order effect’ and ‘learning effect’. Subjects were made aware of the sequence of the rest intervals prior to the initiation of the first set of the first bout.
3.3 Equipment
Subject’s weights were calculated pre-testing using digital weighing scales (SECA, Model 770, Vogel & Halke Hamburg, Germany). A hand held stop watch (Cranlea, Birmingham, UK) was used to time the interset rest periods. The testing was completed on a Smith Machine (Nova fitness, Radstock, UK) for both the squat and bench press protocol. A weight belt was used by all subjects when squatting.

3.4 Testing Procedure
Due to the volume of testing in each protocol and participant time constraints testing was conducted over the course of two days. Subjects completed testing for the squat and bench press on separate days and the rest interval sequence was randomized for both the squat and bench press. Two time slots were allocated to each subject in which there testing would be carried out in the physiology laboratory at UWIC. The subjects were advised not to eat within 2 hours of testing to make sure they were hydrated.

Masamoto et al. (2003) suggest that several minutes of low-moderate intensity exercise followed by various stretching techniques help the performer prepare for the upcoming exercise. It is also duly noted that warming up increases flexibility, reduces injury incidence and enhances performance (Masamoto et al., 2003). In accordance with this subjects were advised to warm up on the Monark cycle ergometers (Monark Exercise, Sweden). Following this subjects were required to perform 2 warm up sets at 50% and 75% (Matuszak et al., 2003) of their individual 4 RM on the Smith Machine (Nova fitness, Radstock, UK) to prime the
specific muscle groups and to familiarise themselves with the equipment and range of motion. Individuals were then able to perform individual stretches of their choice. This warm up protocol was carried out by each subject before both the squat and bench press protocol. The number of successfully completed repetitions in each of the 4 sets at each of 4 rest intervals for the bench press and the squat were recorded for further analysis.

Subjects were provided with water throughout the testing period. Subjects received verbal encouragement from assisting personnel unless the performer was opposed to it (Ware et al., 1995). “Psyching-up”, which refers to self-directed cognitive methods designed to enhance performance were allowed by subjects (Tod et al., 2005).

3.5 Squat Protocol

All squat testing took place on the Smith Machine (Nova fitness, Radstock, UK). The subject positioned themselves under the bar with the bar aligned across the middle portion of the trapezius and posterior to the deltoid (Figure 2). The scapula was retracted to help stabilise the thoracic spine and the hands grasped the bar at a comfortable point (Ware et al., 1995). Two spotters were positioned either side of the machine to assist in re-racking of the bar upon completion of the repetitions and to ensure correct technique was used, for example, hyperextending the lumbar spine (Willardson & Burkett. 2006a). Subjects wore a support belt to assist in correct technique and prevent injury. Upon setting the feet the subject lifted the bar from the rack and began to lower the bar through
flexion at the knee joint until the bottom of the thighs were parallel to the floor. This was observed and judged by the referee a method previously used by Ware et al. (1995). When the bottom of the thigh was parallel to the floor the referee provided a verbal signal and the subject ascended (Matuszak et al., 2003), this represented a full repetition. The squat assesses the strength of hip extensors (glutes, hamstrings, and hip adductors), knee extensors (quadriceps) and spinal extensors (Everett. 2007). Upon completion of 4 consecutive repetitions the bar was hooked back in the rack. If the full range of motion was not executed in the repetition it was excluded and the rep had to be completed again. Failure to complete the first set of 4 reps at 4RM resulted in termination and re-calculation of the load. If the subject was able to complete the 4 maximal repetitions and more on the first set of the testing then the load was adjusted by 2.5kg on the squat as suggested by Willardson and Burkett. 2006b. Rest intervals were timed using a hand held stop watch (Cranlea, Birmingham, UK) and a passive recovery period was implemented due to the findings of Hannie et al. (1995) who revealed that subjects participating in an active rest interval increased the number of repetitions performed. Ten seconds prior to the end of the rest interval the subject positioned themselves under the bar ready to begin on time.
3. 6 Bench Press Protocol
The subjects positioned themselves supine on the bench and gripped the bar approximately 20-30 cm greater than shoulder width with arms extended (Ware et al., 1995). The scapula were slightly retracted and the elbows were positioned out and wrists straight, a technique previously outlined by Everett (2007). With the assistance of spotters, as with the squat, the bar was raised off the rack and slowly lowered through flexion at the elbow joint until the bar touched the chest in line with the nipples (Tod et al., 2005). From this position the bar was raised using the musculature of the chest until the arms were fully extended again, constituting a full repetition (Figure 3). Spotters were present for each repetition in case of momentary failure and the referee made sure correct technique was maintained, for example, making sure the subject’s buttocks remained in contact...
with the bench at all times and that the bar was not bounced off the chest (Ware et al., 1995). The bench press assesses the strength of the chest, anterior deltoid and triceps (Everett, 2007). As with the squat, if the subject fails to complete 4 repetitions the load must be re-calculated. If the subject is unable to complete the 4 maximal repetitions and more on the first set of the testing then the load was adjusted by 1.5kg as proposed by Willardson and Burkett (2006b).

Figure 3: Phases of the barbell bench press motion – (A) Ready position, (B) Downward phase, (C) Ascending phase

3.7 Statistical Analyses
The data was tested for normality using the Kolmogorov–Smirnov test (K-S test).

The Kolmogorov–Smirnov test indicated that the data was not normal. Following this Spearman's rank correlation coefficient, a non-parametric measure of correlation, was applied to the data to establish a relationship between the number of repetitions completed on the squat and bench press. Kruskal-Wallis non-parametric ANOVA was carried out on the data to establish differences between all interset rest intervals for both exercises. A Wilcoxon signed-rank test
(non-parametric alternative to the paired t-test) was then carried out to identify where these differences lie. The statistical significance value was set at $p<0.05$, making the statistical power of the study strong. A theoretical optimal recovery time was calculated using the y-intersect value in the equation for the line of best fit ($y = mx + c$) from individual subject graphs (Appendix C).
CHAPTER FOUR: RESULTS

4.1 Relationship Between Bench Press and Squat
The main finding from the present research study was that the shorter the rest interval between repeated maximal sets, the fewer the mean number of repetitions completed across 7 subjects (Figure 4). Figure 4 demonstrates that 180 seconds rest between sets allows for the most recovery and resultantly the highest number of successfully completed repetitions in both exercises. Spearman’s rank correlation coefficient revealed that there was a relationship between the number of repetitions completed at each rest interval on both the bench press and the squat (p<0.05), as is evidenced in figure 4.

Figure 4: Bar chart representing the mean number of repetitions completed per set across 7 subjects at each interset rest interval.
4. 2 Differences Across Rest Intervals

Figure 4 illustrates that as the rest interval between sets is increased there is a progressive increase in the number of repetitions completed. The progressive increase is more evident in the bench press, where at the 30 second rest interval on average just below 3 repetitions were completed per set, in comparison to just under 4 repetitions at the 180 second rest interval. In contrast, the squat illustrated a minimal difference in the number of repetitions completed at the longest rest intervals (90 and 180 seconds).

Kruskal-Wallis ANOVA test revealed that there were significant differences (p<0.05) in the number of successful repetitions completed between the bench press and squat across all rest conditions. However, the test did not accentuate which rest interval(s) were responsible for the significant difference. The Wilcoxon signed-rank test revealed a statistically significant difference (p<0.05) at the shortest rest interval (30 seconds) (Table 2). This statistical significance is depicted in Figure 4.

**Table 2: Results from the Wilcoxon signed-rank test**

<table>
<thead>
<tr>
<th></th>
<th>Squat30 - Bench30</th>
<th>Squat60 - Bench60</th>
<th>Squat90 - Bench90</th>
<th>Squat180 - Bench180</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>-2.309(a)</td>
<td>-.632(a)</td>
<td>-1.327(a)</td>
<td>-.447(a)</td>
</tr>
<tr>
<td>Asymp. Sig. (2-tailed)</td>
<td>.021</td>
<td>.527</td>
<td>.185</td>
<td>.655</td>
</tr>
</tbody>
</table>

At the 30 second rest interval a statistical significant difference occurred (p=0.21) in the number of repetitions completed in the squat and bench press. The least significant difference (p=0.655) i.e. the most similar in terms of number of
repetitions completed, occurred at the longest rest interval (180 seconds). An interesting finding was revealed at the 90 second rest interval. A greater difference in the number of repetitions completed between exercises was observed at the 90 second rest interval ($p=0.185$) in comparison to the 60 second rest interval ($p=0.527$). This is also illustrated in figure 1.

4.3 Theoretical Optimal Recovery Times

**Table 3:** Theoretical Optimal Recovery Times (seconds) across all subjects, including calculated means for the bench press and squat.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Squat</th>
<th>Bench Press</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>195</td>
<td>314</td>
</tr>
<tr>
<td>B</td>
<td>191</td>
<td>163</td>
</tr>
<tr>
<td>C</td>
<td>206</td>
<td>167</td>
</tr>
<tr>
<td>D</td>
<td>163</td>
<td>234</td>
</tr>
<tr>
<td>E</td>
<td>177</td>
<td>152</td>
</tr>
<tr>
<td>F</td>
<td>151</td>
<td>173</td>
</tr>
<tr>
<td>G</td>
<td>156</td>
<td>181</td>
</tr>
<tr>
<td>Mean</td>
<td>177</td>
<td>198</td>
</tr>
</tbody>
</table>

The amount of time theoretically required for subjects to successfully complete 4 sets of 4 repetitions (16 repetitions) is presented in table 3. The mean across all subjects suggests that the bench press requires a longer rest period between sets (198 seconds) in comparison to the squat (177 seconds) to sufficiently recover. However, the table reveals large inter-subject variability with some
subjects, for example subject E, demonstrating the need for a longer recovery time on the squat (177 seconds) than on the bench press (152 seconds). This is illustrated in figure 5 where subject E optimally recovers on the bench press prior to the squat.

Figure 5: Variability in Subject E - Bench Press and Squat results
CHAPTER FIVE: DISCUSSION

5.1 Discussion

The purpose of the current study was to evaluate the effects of differing interset rest intervals on the ability to reproduce maximal efforts in the squat and bench press, with the intent of establishing an optimal recovery time. Additionally, a lower body and upper body exercise were selected to determine whether there was intra-muscle variability in optimal recovery times for strength exercises.

The present study indicated that the longer the interset recovery time the more sustainable the repeated maximal repetitions were. Thus the 180 second interset recovery time produced the greatest number of repetitions across both the squat and bench press. In contrast, the shorter the recovery period the less sustainable the repetitions were, thus the 30 second recovery period proved the least sustainable. Spearman’s rank correlation coefficient revealed there was a relationship between the sustainability of the squat and bench press (p<0.05). Derived mean theoretical recovery times indicated that the bench press required a longer period of time to optimally recover than the squat (198 seconds and 177 seconds respectively). The Wilcoxon signed-rank test revealed a statistically significant difference (p<0.05) in the sustainability of repetitions at the 30 second recovery interval (p= 0.21).

As a result of the findings, the null hypothesis that there will be no difference in the number of repetitions completed across the 4 rest periods for both the squat and bench press can be rejected in lieu of the statistically significant difference
(p<0.05) in the sustainability of repetitions at the 30 second recovery interval (p=0.21). The alternative hypothesis that the 180 second rest interval will enable the greatest number of repetitions to be completed can be accepted. Furthermore, the hypothesis that the squat will recover more effectively at each recovery period than the bench press can also be accepted (as depicted in figure 4) by a consistently higher mean number of repetitions completed per set.

The key finding from the present investigation, that the longer the interset recovery period the more sustainable the repetitions, is consistent with that of previous studies. Such studies include that of Willardson and Burkett. (2005) using 3 rest intervals, 1 minute, 2 minutes and 5 minutes with an 8 rep max consisting of 4 consecutive sets. The study proved the 5 minute rest interval to be the most sustainable, followed by the 2 minute and 1 minute periods respectively. A further study by Willardson and Burkett (2006b) found that the sustainability of a 15 RM bench press and squat over 5 consecutive sets was significantly different at 30 seconds and 2 minutes (p=0.003 and p=0.000 respectively) with 2 minutes being more sustainable. However, Matuszak et al. (2003) demonstrated the sustainability of a 1 RM back squat over 2 sets at 1, 3 and 5 minutes. Key differences between the three previously mentioned studies are the intensity and number of repetitions being undertaken. It has been noted by Willardson and Burkett (2006b) that sustainability of repetitions over consecutive sets greatly depends on the magnitude of the load lifted and thus the energy system involvement and mechanism of fatigue. Failure to sustain
repetitions in the study by Willardson and Burkett (2006b) has been attributed to the accumulation of hydrogen ions (H+) which lowers intracellular pH resulting in muscle fatigue. It is well established that the adenosine triphosphate (ATP) phosphocreatine (PCr), ATP-PCr energy system is able to sustain energy production for maximal exertion for 10 seconds (McArdle et al., 2006). The time taken to complete 4 repetitions, in the present study, and 8 and 15 repetitions as completed in Willardson and Burkett (2005); Willardson and Burkett. (2006b) takes substantially longer than 10 seconds. Energy expenditure exceeding 10 seconds requires the use of anaerobic glycolysis to turn-over energy. It has also been noted that when the load is decreased the body lies increasingly upon anaerobic glycolysis to maintain energy turn-over for muscular contraction (Willardson & Burkett 2006b). It has also been noted by Willardson and Burkett (2006b) that fast twitch (type IIb) muscle fibres, such as those that comprise the muscles of the quadriceps, rely heavily on anaerobic glycolysis for energy turn-over. As a result the fibres are subject to high level accumulation of H+ resulting in acidosis and inhibition of anaerobic enzyme (ATP-ase and creatine kinase) action resulting in fatigue (Willardson & Burkett. 2006a). According to Willardson and Burkett (2006b) it takes between 4 and 10 minutes for peak cellular and hydrogen ion efflux from contracting skeletal muscle. Therefore, the longer recovery periods between sets, such as the 180 second interval in the present study, would likely allow the fast-twitch fibres an extended period of buffering and clearing of H+ thus allowing for a greater sustainability of repetitions (Willardson & Burkett. 2006b). It has been stated by Lawton et al. (2006) that 3 – 7 minutes
rest is sufficient for contracting tissue to replenish phosphocreatine, facilitate the removal of metabolic end products, restore intramuscular pH and return membrane excitation to baseline levels (Lawton et al., 2006). In the study conducted by Matuszak et al. (2003) subjects only performed 1 RM for 2 sets, with each repetition lasting no longer than 6 seconds. Given that replenishment of PCr stores is rapid, with half of the used PCr being replenished within 30 seconds of recovery (Matuszak et al., 2003; Willardson & Burkett 2006b) all energy for the 1 RM squat is provided by the ATP-PCr system with no bi-products. Additionally, the minimum recovery period is 1 minute which according to the literature, is sufficient for full replenishment of intramuscular ATP-PCr stores and could explain why sustainability was recorded at 1 minute. This can explain why the 30 second rest interval was not sustainable in the present investigation.

As noted by Linnamo et al. (2005) heavy resistance exercise is linked to acute increases in anabolic hormones and growth factors such as GH and T. The presence of these hormones in the blood is associated with acute decreases in neuromuscular function (Linnamo et al., 2005) and decreases in maximal force production (Ahtiainen et al., 2005). If the stimulus from strength training is sufficient, high acute levels of these hormones are present. Linnamo et al. (2005) have linked increased GH and T serum levels to decreased intramuscular pH resulting from increased lactate production. Therefore, metabolic fatigue has a direct link to neural fatigue as increased hormone concentrations are associated
with decreased neuromuscular function (Linnamo et al., 2005). Clark et al. (2006) have indicated that there is a loss in evoked muscular force at high stimulation intensities. It has been stated by Cark et al. (2006) that high intensity and frequency stimulation results in excitation contraction (EC) coupling failure. Excitation contraction coupling failure has been attributed to decreased calcium (Ca²⁺) release by the sarcoplasmic reticulum or decreased contractile protein (troponin in actin filament) sensitivity to calcium, as well as to reduced numbers of cross bridge formations (Babault et al., 2006). It has also been related to disturbances, i.e. increases in extra cellular potassium ions, preventing action potential propagation along the surface membrane blocking conduction along the t-tubules causing greater force output decrements (Clark et al., 2006). This cause of neuromuscular fatigue could be responsible for inability to sustain repetitions in the shorter rest intervals in the present research study, where the frequency of stimulation is greatest.

Richmond and Goddard. (2004) acknowledge the need for the body to rest in order to recover and restore its enzymatic capacity to perform work. However, more importantly it is recognised that there are considerable variations in metabolic recovery rates and enzyme system utilisation within the muscle itself (Richmond & Goddard 2004). This is linked to individual differences in the composition of the specific muscle group and the individual’s fibre type distribution. Skeletal muscle does not consist of a homogeneous group of fibres (McArdle et al., 2006). Seynnes et al. (2007) states that the quadriceps are a
muscle of mixed composition, therefore the proportions of fibre type through the muscle group may differ comparatively to that of the chest. Type II muscle fibres have a higher threshold for excitation and a greater ability to rapidly transmit action potentials and generate rapid crossbridge turnover and are therefore recruited during maximal exercise (Bompa 1999). If a greater portion of such fibres, which are highly fatigueable, are present in the chest rather than in the quadriceps then this could account for the lower sustainability of repetitions across recovery times in the bench press as evidenced in the present study. A further scenario could be that due to the greater CSA of the quadriceps and given that a larger number of individual muscles comprise the quadriceps, that there are more fixators and stabilising muscles in and around the musculature. Therefore there is increased assistance from surrounding muscles contributing to the ability of the quadriceps to maintain a higher repetition output (Bompa 1999). Furthermore, Seynnes et al. (2007) concludes that there can be regional differences in the amount of stimulation that is transmitted across the length of the muscle. It is noted that forces are transmitted laterally through the connective tissue matrix as well as longitudinally to tendon structures (Seynnes et al., 2007). Therefore, intermuscle differences in architecture can lead to differences in the transmission of force to tendon structures along the sarcomeres. This can in turn cause intermuscle differences in stimulation, the amount of force generated along the muscle proximally and distally, and the degree of protein disruption (Seynnes et al., 2007). This could explain the findings of Willardson and Burkett.
(2006b) and the present investigation which conclude that the squat was more sustainable than the bench press across all recovery periods.

5. 2 Practical Implications

Strength training has substantially increased in popularity over the last decade amongst the athletic population seeking to further enhance performance and also in the public sector with individuals looking to improve their health (Hannie et al., 1995). It is therefore of value to understand the most efficient and effective methods of enhancing strength performance, especially amongst strength and conditioning coaches. If resistance training variables, such as interset recovery time, are correctly addressed and understood people can save substantial time and effort. The squat and bench press are two of the most frequently used exercises in resistance programmes (Ware et al., 1995) and thus the findings are of value on a global level. When the training goal is maximal strength it can be advised that 3 or more minutes of rest should be taken between repeated sets to stimulate adaptation. When training maximally on the chest, it is proposed that a longer recovery period between sets should be given.

5. 3 Limitations, Delimitations and Future Research

Delimitations to the study include an all male sample population. Therefore the findings cannot be directly related to strength training in the female population. The sample group was relatively small in comparison to past studies which used 16 subjects \( n=16 \) (Spreuwenberg et al, 2006; Woods et al, 2004; Hannie et al, 1995). Due to the small nature of the sample population in the present study, the data was classified as not normal \( p = <0.05 \) and therefore non-parametric
equivalents were conducted. The sample population was within a narrow age bracket (mean ± SD for age = 21.9 years ± 0.9) therefore, findings cannot be related to the elderly or adolescent populations. However, the age bracket tested accounts for a large portion of the active population involved in strength training programmes.

A number of limitations arise during the present research study, most of which are reflected in the methodology. The pre-determination of individuals 4 RM loads provided a potential flaw. Subjects were asked to calculate their individual 4 RM in their own time so as not to exert excessive time demands and to do so using a repeated 4 repetition method until 4 reps can no longer be completed. This particular method has not been validated and therefore is subject to scrutiny. As with all maximal testing there are psychological issues that result in apprehension and commonly underestimation of load (Kim et al., 2002). However, the method was appropriate in relation to subject availability. Foot positioning on the squat was not regulated and was left to the subject’s digression. A study by Abelbeck. (2002) revealed that when using linear motion track machines, variation in anterior-posterior foot placement occurs causing horizontal forces to be applied to the floor and the machine. Cotterman et al. (2005) found that the fixed motion of the bar on a Smith machine induced alterations in technique, muscle recruitment and force production compared to the free-weight equivalent. Therefore, depending on the subjects foot positioning, the amount of stress on the desired muscle can be affected and thus influence
the power output. In future research foot positioning should be standardised to account for such variations. However, if subjects are forced into anatomical positions that are uncomfortable and unaccustomed to using maximal loads, there is potential for increased injury incidence as the force is being applied in an unaccustomed manner. Although the type of equipment may influence force production, several other more influential variables such as neuromuscular control and fibre type have a more influential affect (Cotterman et al., 2005). Furthermore, psychological apprehension at maximal loads can significantly impact on performance (Tod et al., 2005), thus for the purpose of the present study it was left to the subjects digression.

A key factor influencing the results of the present investigation was that subjects completed all testing for the particular muscle group on the same day. Therefore, the specific muscles were subject to a high volume and intensity in a short time period. The subsequent rest period between bouts of exercise, i.e. time between the different rest periods was not controlled. As noted my Matuszak et al. (2003) there is currently no standard minimal rest period between successive bouts. Therefore, cumulative fatigue from previous exercise bouts may have a profound effect on subsequent performance (Matuszak et al., 2003).

Future research should be conducted into intermuscle variability in recovery properties to accurately assess if there is a general trend amongst muscle size and composition with regard to recovery. It would also be of interest to further
research interset recovery periods at different loads, such as 2 RM, 3 RM and 5 RM as strength training varies between 85%-100% of the 1 RM typically for between 1 and 6 reps of 1-4 ‘working’ sets (Bompa. 1999).

5.4 Conclusion

The findings from the present research study are consistent with that of previous research and support the relevant literature. The findings are of use to strength and conditioning coaches and athletes, who are consistently seeking techniques to optimise adaptations and consequently strength performance. They are also of use to the general public who practice resistance training, they provide general guidelines of recovery for popular exercises.
CHAPTER SIX: REFERENCES


APPENDICES
Appendix A: Physical Activity Readiness Questionnaire (PAR-Q)

**Physical Activity Readiness Questionnaire (PAR-Q)**

*Please circle the answers to the following questions:*

1. Has your doctor ever said you have a heart condition and that you should only do physical activity recommended by a doctor?
   - Yes / No

2. Do you feel pains in the chest when you do physical activity?
   - Yes / No

3. In the past month have you had chest pain when you were not doing physical activity?
   - Yes / No

4. Do you lose your balance because of dizziness or do you ever lose consciousness?
   - Yes / No

5. Do you have a bone or joint problem that could be made worse by physical activity?
   - Yes / No

6. Is your doctor currently prescribing drugs for blood pressure or a heart condition?
   - Yes / No

7. Do you currently have any muscle, tendon or ligament damage that is aggravated or susceptible to further damage as a result of physical activity?
   - Yes / No

8. Do you know of any other reason why you should not do physical activity?
   - Yes / No
If you have answered yes to any of these questions, please add details below. Similarly, if there are any situations which will prevent you from exercising write them here.

Signed............................................................................Date........................................
Appendix B: Informed Consent Form

**UWIC PARTICIPANT CONSENT FORM**

**UWIC Ethics Protocol Number:** APPROVED

**Participant name or Study ID Number:**

**Title of Project:** Establishing an optimal recovery time between repeated maximal strength sets on the squat and bench press

**Name of Researcher:** JAMIE HARRIS

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**Research Investigation Information**

Subjects will be asked to perform a series of repeated multiple maximal strength sets on both the Smith machine bench press and Smith machine squat. Subjects will perform 4 sets of 4 repetitions at their pre-determined 4 repetition maximums (4RM) with 4 varying inter-set recovery times on the squat and bench press. Subjects will receive an ample warm up period where 2 warm up sets at 50% 4RM and 70% 4RM must be undertaken to prepare the specific muscles.
Subjects will have experienced spotters that will spot through each repetition of each set to ensure correct technique and safety is maintained. Subjects will squat and bench to an angle of 90° at the knee and elbow joints respectively.

Following completion of the 4 sets a recovery time of 5 minutes will be allowed before the 2 warm up sets of the next exercise commence (the bench press). The 4 designated recovery times for the squat and bench press are; 30 seconds, 60 seconds, 90 seconds 180 seconds. Subjects will receive verbal motivation throughout the testing and will be informed as the rest period time elapses. Upon completion of the testing subjects will receive a 5 minute recovery period.

Testing Requirements

Subjects are asked to adhere to the following in order to be viable for the study;

- To not have consumed alcohol 48hrs prior to testing
- To not be taking any performance enhancing supplements with the exception of protein
- Ensure you are hydrated prior to and for the duration of testing
- To not have consumed food within 2hours prior to testing
- Ensure you are of good health on the day of testing
➢ To wear comfortable clothing that does not restrict motion and to wear proper sports trainers with sufficient ankle support

Participant to complete this section: Please initial each box.

1. I confirm that I have read and understand the information sheet dated ....................... for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my relationship with UWIC, or my legal rights, being affected.

3. I understand that relevant sections of any of research notes and data collected during the study may be looked at by responsible individuals from UWIC for monitoring purposes, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records.
4. I agree to take part in the above study.

Signature of Participant: .................................................................

Date........................................................................................................

Name of person taking consent: ...........................................................

Date........................................................................................................

Signature of person taking consent

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Appendix C: Theoretical optimal recovery time graphs for each subject

C.1 Subject A

\[ y = 0.019x + 10.036 \]
\[ y = 0.0262x + 10.893 \]

C.2 Subject B

\[ y = 0.0357x + 10.286 \]
\[ y = 0.0238x + 11.607 \]
C. 3 Subject C

\[ y = 0.0333x + 10.5 \]
\[ y = 0.0262x + 10.643 \]

C. 4 Subject D

\[ y = 0.031x + 10.964 \]
\[ y = 0.0167x + 12.25 \]
C. 7 Subject G

Interse Rest. Duration (seconds)

Total Repetitions Completed

- $y = 0.0429x + 8.3929$
- $y = 0.019x + 13.036$

Bench
Squat
Linear (Bench)
Linear (Squat)