Strongman: Strength and Conditioning Practices, and the Inter-relationships between Strength, Anthropometrics and Performance

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Master of Health Science (MHSc)

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School of Sport and Recreation

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made.

This thesis fulfills the Auckland University of Technology Master of Health Science guidelines by constructively critiquing previous literature pertinent to the sport of strongman. This thesis provides a broad experimental application to this growing body of knowledge.

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PUBLICATIONS AND PRESENTATIONS

The publications listed below are a result of the research conducted in partial fulfillment of the Masters degree in Health Science.

Articles in-press or under review

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(Paul Winwood 90%, Justin Keogh, Nigel Harris and Lisa Weaver 10%)

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(Paul Winwood 90%, Justin Keogh and Nigel Harris 10%)

The student was the primary contributor (90%) of the research in this thesis and the subsequent analysis and interpretation of the research results. The student was also the main contributor (90%) to the writing of research ethics applications, progress report and papers, as well as being the sole presenter of the research results at conferences. All co-authors have approved the inclusion of the joint work in this thesis.

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Signature: — Signature: ……………………………...

Date: 22/2/2011 — Date: ………………………………..

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ABSTRACT

The sport of strongman is relatively new hence specific research investigating this sport is currently very limited. Elite strongman competitors can pull trucks weighing over 20 tonnes, yet no evidence exists in the scientific literature detailing how these men train to tolerate the physiological stresses accompanied with such high loading. Furthermore, little information exists in the scientific literature as to what determinants contribute to successful strongman performance. The exploratory and experimental studies in this thesis sought to describe the strength and conditioning practices employed by strongman competitors, and to determine the inter-relationships between anthropometrics and maximal isoinertial strength to strongman performance.

In study one, 167 strongman competitors completed a 65-item online survey. The findings demonstrated that strongman competitors incorporate a variety of strength and conditioning practices that are focused on increasing muscular size, and the development of maximal strength and power into their conditioning preparation. The farmers walk, log press and stones were the most commonly performed strongman exercises used in a general strongman training session by the survey respondents. The survey revealed that strongman competitors vary their training and periodically alter training variables (i.e. sets, reps, loads) during different stages of their training. The type of events (i.e. maximum effort or reps event) in a competition can determine loading strategies, and competitors determine the most efficacious training protocols for each event.

Study two established that body structure and common gym based exercise strength are meaningfully related to strongman performance in novice strongman athletes. Twenty-three semi-professional rugby union players with some strongman training experience (22.0 ± 2.4 yr, 102.6 ± 10.8 kg, 184.6 ± 6.5 cm) were assessed for anthropometry (height, body composition, and girth measurements), maximal isoinertial performance (bench press, squat, deadlift and power clean), and strongman performance (tyre flip, log clean and press, truck pull and farmers walk). The magnitudes of the relationships were interpreted using Pearson correlation coefficients, which had uncertainty (90% confidence limits) of ~ ±0.37. The highest relationship observed was between system force (body mass + 1RM squat) and overall strongman performance ($r = 0.87$). Clear moderate to very large relationships existed between all strongman events and the squat (r = 0.61-0.85), indicating the importance of maximal squat strength to successful strongman performance. Flexed arm and calf girth demonstrated the strongest interrelationships of all anthropometric measures with overall strongman performance (r = 0.79 and 0.70 respectively).

This thesis provides the first evidence of how athletes train for the sport of strongman and what anthropometric and maximal strength variables may be most important in the sport of strongman. Strongman competitors and strength and conditioning coaches can use the data from the training practices study as a review of strength and conditioning practices and as a possible source of new ideas to diversify and improve their training practices. The correlation data can be used to help guide programming, which can be used to help maximise the transfer of training to strongman performance and therefore improve training efficiency.

CHAPTER 1. PREFACE

1.1 Thesis Rationale and Significance

The job of the strength and conditioning practitioner is to provide training programmes that can maximise the transfer of training to competition performance. It is this pursuit of optimal competition performance that has athletes and strength and conditioning coaches looking for innovative ways to elicit performance gains.

In the past decade, the sport of strongman has recorded a surge in popularity in many countries, both as a spectator sport and in terms of the number of active competitors. Strongman events are deemed, arguably, more functional than traditional gym based training methods and may have some advantages over traditional gym based resistance training approaches. For example, traditional gym based training exercises are generally performed with two feet side by side and require the load to be moved in the vertical plane (Keogh, Payne, Anderson, & Atkins, 2010c). Strongman events such as the farmers walk, sled pull and truck pull represent functional movements in multiple planes and challenge the whole musculoskeletal system in terms of strength, stability, and physiological demands (McGill, McDermott, & Fenwick, 2009). As a result of these perceived benefits, many strength and conditioning specialists are beginning to incorporate strongman exercises into the conditioning programmes of many of their athletes (Baker, 2008; Hedrick, 2003). However, little is known about these unique training methods and the lifting of ‘awkward’ objects. Elite strongman competitors have been observed in international competitions pulling trucks weighing in excess of 20 tonnes. How did these men get so strong? What unique training methods do they employ for their bodies to tolerate the massive physiological stresses accompanied with such high loading? Currently, a paucity of evidence exists to answer these questions. Such information on the training practices of strongman competitors would offer a source of collective ideas that athletes and strength and conditioning coaches could incorporate into their own practices.

Maximal strength and anthropometric characteristics are a major factor in determining performance across a variety of sports. Evidence suggests that maximum strength and some anthropometric characteristics can be strongly related to sports performances that rely on speed and power, however the exact association between measures of maximum strength, anthropometry and performance are not well understood (Stone, Moir, Glaister, & Sanders, 2002). Understanding how strength and anthropometry relate to performance of a specific event or sport, is a key issue in maximising the transfer of training to performance and therefore improving training efficiency (Pearson, Hume, Cronin, & Slyfield, 2009). Various strength, and anthropometric variables have been tested in sports to evaluate the effects of training (Marey, Boleach, Mayhew, & McDole, 1991), to select athletes (MacDougal, Wenger, & Green, 1991), to distinguish among different competition levels (Keogh, et al., 2009b) and to predict performance (Zampagni, et al., 2008). The rationale behind this approach is that the aforementioned variables are important for movement performance. However, no peer-reviewed literature has examined the strength and anthropometric determinants of successful strongman performance. Examining these variables would help to develop our understanding as to their importance in strength and power sports such as strongman. Such data could help guide programming and be used by strongman competitors and strength and conditioning coaches in terms of what aspects of performance the athletes should focus on during training.

Currently, there appears to be an almost complete lack of scientific study into the sport of strongman. Only four studies so far have been published on the science of strongman training (Berning, Adams, Climstein, & Stamford, 2007; Keogh, Newlands, Blewett, Payne, & Chun-Er, 2010b; Keogh, et al., 2010c; McGill, et al., 2009) with the emphasis being on the metabolic and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of these exercises. This thesis will provide a substantive and original contribution to our knowledge and understanding of the sport of strongman and contribute to the field of strength and conditioning. This will be achieved by conducting two studies: 1) The strength and conditioning practices of strongman athletes and 2) The inter-relationships between maximal strength, anthropometrics, and strongman performance. These studies will inform practice and give new insights and information into how strongman competitors train and the determinants of successful strongman performance.

1.2 Research Aims and Hypotheses

The major aims of the work in this thesis were to:

1) To describe the common as well as unique, strength and conditioning practices employed by strongman competitors.

2) To determine the anthropometric and maximal strength correlates of a number of common strongman exercises in a group of resistance-trained males with experience in strongman training.

The following hypotheses were generated for the studies undertaken in this thesis:

1) Strongman competitors use a variety of scientifically based strength and conditioning practices.

2) Strong interrelationships exist between maximal strength (1RM) and anthropometric variables and strongman competition performance in novice strongman competitors.

1.3 Research Design

Two studies were carried out to achieve the aims and test the hypotheses:

1) To determine the training practices of strongman competitors an exploratory descriptive study was employed. Strongman competitors completed a survey adapted from that used with elite powerlifters (Swinton, Lloyd, Agouris, & Stewart, 2009).

2) To determine the inter-relationships between strength, anthropometrics, and strongman performance a correlation design was used. A group of semi-professional rugby union players were assessed for maximal strength, anthropometrics and strongman performance on different days across a 10-day period during the pre-season.

1.4 Originality of the Thesis

1) Currently, there is very little evidence that exists in the scientific literature detailing how strongman competitors train.

2) Little evidence exists as to what strength and anthropometric determinants contribute to successful strongman performance.

3) No study has investigated the training practices of strongman competitors.

4) No study has examined the inter-relationships between maximal strength, anthropometrics and strongman competition performance in novice strongman competitors.

1.5 Thesis Organisation

This thesis consists of six chapters. Chapter two is a review of the literature and explores the theory of training practice and the key variables of training practices represented in study one (exercise selection, training protocols, training organisation, and specific strongman training). These are explored in detail and synthesised with the evidence base. The current literature on strongman is also examined. Chapter three is an exploratory study on the strength and conditioning practices of strongman competitors. Chapter four is a review of the literature that explores the biomechanical factors that are involved in the manifestation of human strength and the relationships between maximal strength (1RM), anthropometrics, and movement performance. Subsequently, it reviews studies that have investigated the relationship among these variables and their ability in predicting performance. Chapter five is an experimental study in which the inter-relationships among maximal strength, anthropometrics and strongman performance are examined. The final chapter consists of general conclusions and recommendations for athletes and strength and conditioning practitioners. An overall reference list from the entire thesis has been collated at the end of the final chapter in APA (6th ed.) format. An abbreviations and glossary section has been included after the reference list to help guide the reader if required. The appendices present all the relevant material from the studies including the abstracts from the two scientific studies, ethics approval, participant information sheets, questionnaires, informed consent forms, and summaries of literature. Due to the scope of this project two literature reviews were written that summarise the research pertinent to each of the two scientific papers presented in this thesis. The reviews clearly demonstrate the deficiencies in our current knowledge about the sport of strongman and establish the significance of the scientific studies presented in chapters three and five. Please note that there is some repetition between the literature reviews and the introductory material of the experimental chapters, owing to the format in which the overall thesis is presented.

CHAPTER 2. STRENGTH AND CONDITIONING PRACTICES: A REVIEW OF THE LITERATURE

2.1 Prelude

Humans have always been drawn to the mystic of strength; as such, training practices in the pursuit of strength have been recorded for thousands of years. Interior walls of Egyptian tombs carry illustrations denoting the practice of swinging exercises employing stone or lead weights. An archaeological examination of ruins in ancient India show a culture engaged in similar forms of physical training (Brzycki, 2000). The art galleries of Florence and Rome showcase the finely developed athletes of old from a time when their arms were weapons and their lives depended on their physical strength (Sandow, 1897).

Strongmen demonstrating feats of incredible strength have been around for centuries. It was an Englishmen Eugen Sandow, known as the ‘father of modern bodybuilding’ who transformed physical culture in the twentieth century (Daley, 2002; Schwarzenegger, 1998). Sandow demonstrated and adapted the Grecian ideal that it was possible to bring the body to its highest possible state of power and beauty (Sandow, 1897). He became a professional strongman and astounded audiences throughout the world with his feats of strength and physical prowess.

Recently, the sport of strongman has recorded a surge in popularity in many countries, both as a spectator sport and in terms of the number of active competitors. Part of this reason may be due to the unique events demonstrated in the sport, the accessibility of the training implements and the opportunity to add variation to resistance training programmes. Elite competitors compete professionally around the world, and gather each year to compete for the World’s Strongest Man title. Each strongman competition is unique and has its own individual events such as; the Atlas stones, the farmers walk, tyre flipping, and the truck pull. Observations of elite strongman competitors competing in strongman competitions suggest that they have exceedingly high levels of muscular hypertrophy, total body muscular power, strength and endurance, core stability and anaerobic endurance. As a result, many strength and conditioning specialists are beginning to incorporate strongman exercises into the conditioning programmes of their athletes (Hedrick, 2003).

Generally, most traditional gym based resistance training exercises are vertical in nature and are performed with the two feet side by side. In contrast, human gait consist of walking and running, which involves predominantly horizontal motion that occurs as result of unilateral ground reaction force production (Hamill & Knutzen, 2009). While walking lunges or split stance exercises may offset some of the limitations of the traditional lifts (Keogh, 1999a), strongman exercises may be even more applicable as they often involve unstable and awkward resistances and would appear to require the production of high horizontal as well as vertical unilateral forces. Randell, Cronin, Keogh & Gill (2010) suggest that athletes could improve their performance, if the design of their resistance training programme focuses on horizontal movement-specific exercises as well as traditional vertical exercises.

McGill, McDermott, & Fenwick (2009) suggested that strongman exercises may have some advantages over more traditional gym based resistance training as they represent functional movements in multiple planes and challenge the whole musculoskeletal system in terms of both strength, stability and physiological demands. The inclusion of strongman exercises such as the tyre flip, truck pull, farmers walk and yoke walk along with more common lifts such as the power clean, deadlift and squat may therefore further improve the performance of many athletic groups.

It is widely known that resistance training can increase muscle force production, which is critical for sports performance. Many sports, including strongman require the ability to not only move a heavy mass, but to move that object quickly and/or over relatively large distances. Therefore, it is necessary to develop resistance training programmes that not only improve strength, but also rate of force development, power and muscular endurance. However, various training protocols illicit different strength and power characteristics (McBride, Triplett-McBride, Davie, & Newton, 1999).

Currently, no evidence exists in the scientific literature for what actually constitutes 'typical" strongman training and how traditional gym based strength and anthropometry may influence performance in strongman competitions. This review explores the theory and application of training practice and examines the current literature on the sport of strongman.

2.2 Introduction

The first documented progressive resistance training practices, were recorded in Greece in the 6th century B.C. Milo of Crotona, military hero and six times Olympic champion was said to have lifted a calf everyday until it was a fully grown bull (Atha, 1981). Milo's great strength may have come through the gradual process of adaptation. Dowson (1999) suggested that for an athlete to develop, workloads have to be demanding on the body. This adaptation takes place if the workloads are regular and are at a level above those normally encountered. Figure 1 presents the response to a training session. This is known as the 'training effect' and incorporates the principle of progressive overload. Progression is defined as "the act of moving forward or advancing towards a specific goal" (American College of Sports Medicine, 2002, p. 364). Overload consists of exercise and training that 'force' the athlete beyond normal levels of physical performance (Stone, Stone, & Sands, 2007). In resistance training, progression entails the continued improvement in a desired variable (e.g. strength) over time until that target goal is achieved. Another key concept of the training principles of adaptation and progressive overload is that the training stimulus needs to be changed regularly otherwise performance will plateau (the point in time where no further improvements takes place). Without variation it is impossible for an athlete to continually improve at the same rate with long-term training. With the appropriate manipulation of programme variables (exercise selection and order, training volume, exercise and training intensity factors, training density and speed of movement) it is possible to limit training plateaus and consequently enable achievement of higher levels of muscular fitness (American College of Sports Medicine, 2002).

Figure 1 illustrates the four phase process, fatigue, adaptation, plateau and detraining. This figure originated from the work of Hans Selye who first began piecing together the nature of human stress. The training stimulus causes fatigue and during the post workout recovery the body responds and adapts to the specific stimulus in which it was stressed e.g. cardiovascular or neuromuscular stress. The body then reaches a plateau where no further improvement takes place. This concept is important to understand as if there are no more sessions, or the next session follows too long after the previous session, detraining occurs, and performance adaptations are reversed (Dowson, 1999). Furthermore, the adaptive processes of the human body will only occur if continually called upon to cope with a greater stimulus than previously encountered. However, this will only occur providing the body is allowed sufficient recovery between training stimuli. An inadequate amount of recovery in combination with too much training will lead to detraining. Signs and symptoms of over-training can be increased injury (e.g. shin splints) and reduced performance (up to 20% decline) (Dowson, 1999).

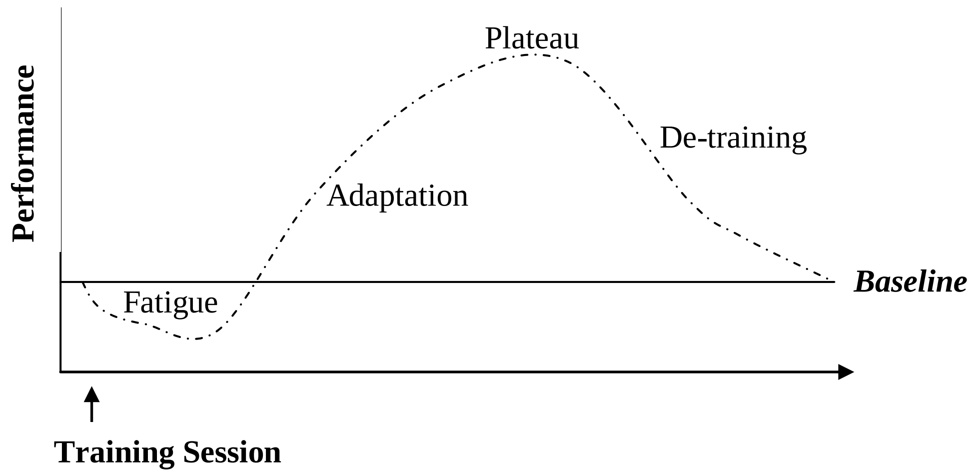

Figure 1: The training effect and the principle of adaptation (Adapted from Dowson, 1999, p. 11).

Athletes need the training stimuli to result in an observable improvement in their performance; therefore the adaptive processes need to be sports specific. This can however be quite complex considering all the variables that relate to sports performance (movement patterns, muscle action type, peak force, and rate of force development, acceleration, and velocity parameters). Understanding how training stimuli can effect adaptations is paramount for the strength and conditioning coach. In today’s competitive sporting world, differences between winning and losing can be infinitesimal. Understanding how to implement the best training stimuli to elicit optimal adaptations would be advantageous. As such, researchers have sought to examine training practices across a variety of sports to provide insight into training practices and their relationship to sports performance. Researchers have focused on aerobic training and injury (Walter, Hart, Sutton, McIntosh, & Gauld, 1988), aerobic training and periodisation (Fulton, Pyne, Hopkins, & Burkett, 2010; Liow & Hopkins, 1996), and resistance training practices of strength and conditioning coaches and athletes (Tables 1 and 2 respectively). The knowledge gained from such research can help guide strength and conditioners into prescribing optimal resistance training programmes that can benefit athletes in various sports.

Table 1: Summary of the resistance training practices of strength and conditioning coaches.

Study	Subjects	Methods	Results					
			Periodisation	**Olympic lifts**	**Plyometrics**	**Most important exercises**	**High intensity training**	**Flexibility training**
Ebben et al. (2001)	26 National football league strength and conditioning coaches	Survey	69.0%	88.0%	94%	Squat & variations & Olympic lifts	71% who followed a non-periodised model	100%
Ebben et al. (2004)	23 National hockey league strength and conditioning coaches	Survey	91.3%	100%	100%	Squat & variations & Olympic lifts	Not stated	95.7%
Ebben et al. (2005)	21 Major league baseball strength and conditioning coaches	Survey	85.7%	14.3%	95%	Squat	19.2%	100%

Simenz et al. (2005)	20 National basketball strength and conditioning coaches	Survey	85.0%	95.0%	100%	Squat & variations & Olympic lifts & variations	Not stated	100%
Duehring et al. (2009)	38 High school strength and conditioning coaches	Survey	95.0%	97.4%	100%	Squat & variations & Olympic lifts & variations	Not stated	97.4%

The % indicates those who use such methods in their training.

Table 2: Summary of the resistance training practices of athletes, and strength and conditioning coaches.

Study	**Subjects**	**Methods**	**Results**			
			Resistance training	**Training habits**	**Frequency & Volume**	**Injuries**
Athletes						
Katch et al. (1980)	39 males 18 bodybuilders 13 powerlifters 8 Olympic weight lifters	Survey	All use resistance strength training	41% of subjects performed aerobic conditioning	Bodybuilders-2hrs a day, 5 days a wk Olympic weight lifters-2.25hrs a day, 5 days a wk Powerlifters-2hrs a day, 4 days per wk	Not stated
Hedrick et al. (1988)	36 elite wheelchair racers (Open men, women, & quadriplegics).	Survey	Higher % of men did weight training than women	Aerobic and anaerobic interval training	2 to 3 60min weight training sessions per wk. Open men had highest mileage across all quarters	Not stated
Watanabe et al. (1992)	39 athletes (various sports & disabilities)	Survey	22% of athletes did no weight training	2 weight training sessions per week.	4.1 workouts per wk of 2.1hrs. Wheelchair athletes did more miles per week	Not stated
Stanton et al. (2002)	101 Australian outrigger canoe paddlers	Survey	71% use strength training	74% use additional cross training 3.1 times per wk	3.2 on water sessions per wk lasting 1.7hrs	49% report injuries.

Newsham-West et al. (2009)	199 masters level football players	Survey	% of players doing weight training decreased with age	84% players include warm up, 78% include stretch routine	1 to 4hrs per wk	93 players reported injuries.
Swinton et al. (2009)	32 elite British powerlifters	Survey	All use. Majority train explosively with maximal and sub maximal loads	39% use elastic bands and 57% use chains, 69% use Olympic lifts. 96.4% use periodisation	Not stated	Not stated
S&C Coaches						
Reverter-Masia et al. (2009)	77 S&C coaches from elite Spanish club teams	Survey	All used, except 1 indoor soccer team and 2 field hockey teams	Squat and bench press most used exercises. ‘A’ teams used optimal training loads	Not stated	Not stated

Key: S&C = Strength and conditioning, hrs = hours, wks = weeks, min = minutes.

2.3 Exercise selection

Specificity of exercise and training is one of the most important considerations for sports performance enhancement. For example, a programme for a rugby player wishing to increase his maximal strength will differ greatly from a cyclist wishing to increase his muscular endurance. Understanding the factors that go into creating the specific 'exercise stimulus' is crucial in designing resistance training programmes (Kraemer, Hatfield, & Fleck, 2007).

It is widely documented that strength gains reflect both neural and morphological adaptations. Examples of neural adaptations include increases in motor unit firing rate and synchronisation (Gabriel, Kamen, & Frost, 2006) whereas morphological adaptations may involve an increase in cross-sectional area (CSA) of the whole muscle (Folland & Williams, 2007). These adaptations result in greater muscle recruitment to perform a particular type of muscle action. Training programmes need to include exercises that incorporate the muscles and the types of muscle actions encountered in the sport (Fleck & Kraemer, 1997). Furthermore, training programmes need to incorporate exercises that target the main agonists, specific joint angles and direction of force application, muscle sequence patterns, specific postures, and velocities of movement, and core stability requirements, as they are all important aspects of training specificity. The more similar a training exercise is to actual physical performance, the greater the probabilities of transfer (Stone, et al., 2007).

Having an understanding of overload factors can aid in the selection of exercises and equipment, particularly free weights versus machines. Most machines are designed for the performance of single-joint or small muscle mass exercises that do not require as much energy expenditure per repetition as large muscle mass exercises like the barbell squat (Stone, et al., 2007). This can affect body composition as decreases in body fat are related to total energy expenditure. Free weight exercises like the deadlift and squat are well known for their ability to enhance strength (Fleck & Kraemer, 1997). These multi-joint exercises recruit large amount of muscle mass, initiate greater hormonal responses and metabolic demands, have higher energy expenditure and greater transferability to sports performance compared to training with small muscle mass exercises (Stone, et al., 2007).

Fleck and Kraemer (1997) suggested multi-joint exercises should be performed first while in a rested state as they require fine motor coordination and maximal neuronal output. Many experts believe that exercising the larger muscle groups first provides a superior training stimulus to all of the muscles involved (Kraemer, et al., 2007). The rationale behind this may be that an athlete is able to apply greater resistance to the muscles since they are not yet fatigued, allowing for a greater training effect. Free weight multi-joint exercises can however be complex (e.g. power clean), requiring coaching and experience to perfect proper form. Altering the proper form of an exercise causes other muscle groups to assist in performance of the exercise movement, which can decrease the training stimulus on the muscles normally associated with the exercise (Fleck & Kraemer, 1997). Therefore training sessions must be designed to fit the needs of the athlete in regard to exercise selection and order, and resistance training experience.

Recently, Reverter-Masia and colleagues (2009) found that large differences existed among strength and conditioning coaches in elite Spanish club sports teams, in regard to exercise selection. The sports teams included; handball, basketball, volleyball, indoor soccer, soccer and field hockey. The bench press, shoulder press, hip, thigh and calf exercises were the only exercises used by more than 50% of the teams. Surprisingly, one indoor soccer team and two field hockey teams did not even include weight training exercises in their training programmes. In contrast, similarities were reported among strength and conditioning coaches in football (Ebben & Blackard, 2001), ice hockey (Ebben, et al., 2004) and baseball (Ebben, et al., 2005). Ebben and colleagues observed that all strength and conditioning coaches reported that the squat was the number one choice of exercise and the power clean, lunge, and variations of the row and bench press were in their top five choices of exercises. The studies show that even though National football league (NFL), National hockey league (NHL) and Major league baseball (MLB) are all very different sports, the strength and conditioning coaches believe that the specific free weight exercises selected may have kinetic and kinematic relationships to their sporting activities and consequently transfer well to their sports.

Exercise selection was also one of the areas of inquiry in a recent study of 28 elite British powerlifters (Swinton, et al., 2009). In the sport of power lifting, powerlifters attempt to lift a maximal load for one repetition (1RM) in the squat, deadlift and bench press. One of the questions in the survey of Swinton et al. (2009) asked was what assistance exercises the powerlifters felt best improved the squat, bench press and deadlift. Interestingly, box squats were cited most frequently for the squat (29%), close grip bench press was cited most frequently for the bench press (43%), and platform deadlifts were cited most frequently for the deadlift (29%). The corresponding percentages are however fairly low suggesting that variability exists among elite powerlifters in what assistance exercises they believe best improves lifting performance. Findings from this research also demonstrated that 60.7% of the powerlifters incorporated the power clean in their training practices. The power clean is one part of the weightlifting clean and jerk movement. Both sports require the lifter to lift the maximal load for one repetition, however the movement velocities between the sports differ greatly with weightlifting producing the greatest power outputs of any activity (Garhammer, 1993). Swinton and colleagues (2009) suggested that elite powerlifters include Olympic lifts as a means of developing power and whole-body explosiveness.

Strongman events have many similarities to weightlifting and powerlifting. For example, athletes performing the 1RM log press attempt to lift the heaviest load possible for one repetition above their heads. Other strongman events are timed, such as the farmers walk and Yoke walk, which require the athlete to carry heavy loads over a specific distance as fast as they can (Keogh, 2010). Unfortunately, it is not known what resistance exercises strongman competitors incorporate into their resistance training programmes or what assistance exercises they believe best improves their performance in strongman events.

2.4 Training Protocols

Different training protocols can elicit different mechanical, hormonal, and metabolic stresses on the system and hence result in varying responses (Crewther, Cronin, & Keogh, 2005; Crewther, Cronin, & Keogh, 2006a; Crewther, Keogh, Cronin, & Cook, 2006b). Therefore, it is essential that strength and conditioning coaches and athletes understand the variables (load, frequency, rest, reps, sets) associated with training protocols and their effects on physiological responses. Table 3 (Adapted from Fleck & Kraemer, 1997, p. 101) demonstrates how the manipulation of these variables may influence physiological responses with resistance training.

Table 3: How the manipulation of variables influences physiological responses (Adapted from Fleck & Kraemer, 1997, p. 101).

	Strength	Hypertrophy	Power	Endurance
Load (%1RM)	85-100	60-85	30-60	30-60
Reps	1-7	8-12	1-6	12+
Sets	4-10	3-20	4-10	2-3
Rests	Long	Short	Long	Short
Velocity	Slow	Moderate	Fast	Moderate

Training intensity is associated with the rate of performing work and the rate at which energy is expended, and training volume is the measure of how much total work is performed and the total amount of energy expended (Stone, et al., 2007). Research suggests that muscular hypertrophy (increase in size of muscular fibres) and neuromuscular determinants are affected by load and intensity (Fry, 2004). The manipulation of load (as an expression of 1RM) can vary the morphological and neurological responses. Training programmes designed to produce the greatest change in muscle CSA are often characterised by loads of approximately 60-70% 1RM (MacDougal, 1992) while programmes designed to enhance strength through enhanced neural coordination are typified by intensities of 85-100% 1RM (Fleck & Kraemer, 1997; Komi & Hakkinen, 1988). Heavier resistances (e.g. >85%) require the recruitment of higher threshold motor units, which are composed of predominantly Type II fibres (Fleck & Kraemer, 1997). The heavier resistances give a greater training effect in the Type II fibres and hence increase force output. These Type II fibres are the predominant fibres for anaerobic work and can be further divided into Type II A and II B fibres that that rely on glycolytic and ATP-PC energy sources, respectively (Aaberg, 1999).

Training intensity and volume load has been related to competitive performance among elite weightlifters training for the 2003 world championships (Stone, et al., 2007). Correlations between repetitions and performance were low ($r = <0.2$), however correlations between average and total volume load and performance were quite high ($r = 0.72-0.73$) respectively, and training intensity was very strongly correlated with final performance ($r = 0.96$). The results suggest that the appropriate training intensity will provide the proper stimuli for eliciting specific physical, physiological and performance adaptations. Yakovlev's model of training and adaptation (Figure 2) demonstrates that training at the appropriate intensity will help to elicit the best performance adaptations', providing the training programme is designed to create the optimal overload stimulus.

Supercompensation – adaptation process – correct compromise between loading and recovery

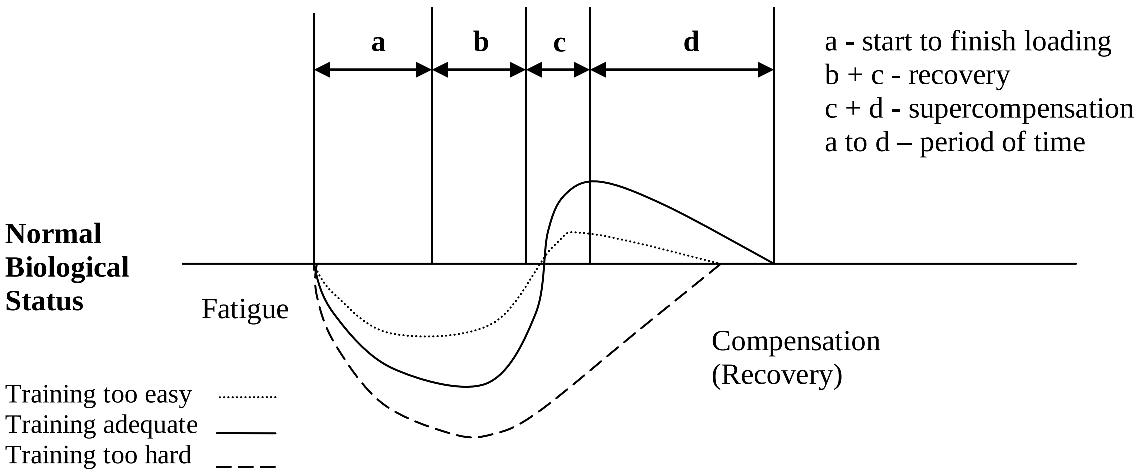

Figure 2: Soviet sport scientist N. Yakovlev's model of training and adaptation (Adapted from Grant, 2003).

The manipulation of training load appears able to affect muscle fibre type characteristics. Bodybuilders have a greater percentage of Type I fibres than weightlifters and powerlifters, who conversely, had a greater percentage of Type II fibres than bodybuilders (Fry, 2004; Tesch & Larsson, 1982). Reasons for these differences may be due to the types of training and training loads used. Bodybuilders spend considerable amounts of training time using loads ≤80% 1RM whereas weightlifters and powerlifters train specifically to increase their 1RM capabilities, and thus routinely use loads approaching 100% 1RM. Bodybuilding differs from the other weight-lifting sports as it is judged on the physical appearance of an athlete rather than the weight lifted in competition (Keogh, 2010). Bodybuilders train to isolate and exhaust individual muscle groups, with a higher overall training volume, coupled with a moderate training intensity (expressed as a percentage of 1RM) and minimal rest periods between sets and exercises. Interestingly, the study of Tesch and colleagues (1982) found that the bodybuilders Type 1 fibres were of normal muscle fibre size but there were many more of them. These findings may reflect exercise induced formation of new muscle fibres, either by satellite cell activation and/or longitudinal fibre splitting (hyperplasia) as a response to hypertrophy resistance training.

Differences in the training loads among elite teams are also apparent. A similar load intensity of 70 to 90% of 1RM was found across all sports in elite Spanish club teams (Reverter-Masia, et al., 2009). Interestingly, the study showed that the majority of class ‘A’ teams (95%) worked with the training load 70-90% compared to only 74% of the class ‘B’ teams. This difference may reflect knowledge deficits and experience in resistance training by the coaching and support staff of these teams. Fry (2004) suggested that the optimal hypertrophy intensity range is between 80 and 90% of 1RM which is higher than 60-70% suggested by MacDougal (1992). However the load range of 80 to 90% of 1RM has shown to produce the greatest combination of mechanical, metabolic, and hormonal responses (Crewther, et al., 2005; Crewther, et al., 2006a). Havelka (2004) suggested that to train for the strongman event, the log press, a weight in the region of 75-85% 1RM should be used. However, no research exists in the scientific literature that demonstrates what percentage of 1RM strongman train with, or if they train with loads lighter, the same or heavier than they would encounter during competition.

The frequency of training in the sport of strongman has not been investigated. It has however been investigated in the weightlifting sports (Katch, et al., 1980). Interestingly, Olympic weightlifters and bodybuilders trained five days per week compared to four days for powerlifters. However, Olympic weightlifters trained 2.25 hours per day compared to 2 hours for bodybuilders and powerlifters. Of the three weightlifting sports Olympic weightlifters were found to have the highest amount of training hours per week (11.25), compared to bodybuilders (10.0) and powerlifters (8.0). This may reflect that the complex nature of Olympic lifting (i.e. the snatch and clean and press) requires more time and practice than the traditional lifts performed in powerlifting (i.e. squat, bench press and deadlift). In the sport of strongman exercises like the tyre flip and Atlas stones are similar to the deadlift and clean, however it is not known how many hours/days per week strongman competitors train for or how many training sessions they perform doing traditional lifts versus strongman lifts.

Recently, the frequency of training was examined using a sample of 101 Australian outrigger canoe paddlers, with the data obtained via a hand delivered questionnaire (Stanton, et al., 2002). Like strongman, outrigger canoe is a relatively new sport and little is known on its training habits. While 71% of paddlers used strength training 2.5 times a week to accompany paddling, and 74% reported additional cross training 3.1 times per week, Stanton et al. (2002) reported that paddlers were not well informed about fundamental training practices. It is also not known how well informed strongman competitors are about resistance training practices. Both strongman and outrigger canoeing sports are relatively new and the ‘right’ training practices may still be evolving.

The number of sets depends on the exercise volume desired (Fleck & Kraemer, 1997), and exercise volume can determine metabolic (Crewther, et al., 2006a) and hormonal responses (Schwab, Johnson, Housh, Kinder, & Weir, 1993). Sets and repetitions (reps) during off-season and in-season programmes have been examined in football (Ebben & Blackard, 2001) and baseball (Ebben, et al., 2005). Large differences between strength and conditioning coaches were reported within the sports and between the sports. Off-season ranges of sets and reps in the National football league (NFL) were 1-7 and 1–50 respectively and in the major league baseball (MLB) 2-6 and 5-15 respectively. Only a very small number of the MLB and NFL strength and conditioning coaches showed a strength progression programme. The large differences of sets and reps between strength and conditioning coaches in the NFL may indicate that some strength and conditioning coaches might be lacking some aspects of the fundamental knowledge of the scientific principles of resistance training. However, it is not yet known how well strongman competitors understand the principles of resistance training or how they are applying them.

The effectiveness of a strength resistance programme can be directly related to the rest provided to the muscles between sets, between days of training and before competition. Muscles that have been stressed through resistance training need rest for the recovery and rebuilding of muscle fibres (Hamill & Knutzen, 2009). The rest period between sets and exercises affects the muscles responses to resistance exercise and influence how much of the Adenosine Triphosphate Phosphocreatine (ATP-PC) energy source is recovered. Programmes using short rest periods (30-90 seconds) with moderate to high intensity and volume, elicit greater acute responses of anabolic hormones than programmes using very heavy loads and longer rest periods (Kraemer, et al., 1991). Shorter rest periods are associated with greater metabolic stress (e.g. higher levels of lactate in the blood), and metabolic stress is a stimulus for hormone release (Kraemer, et al., 2007). The hormonal release is needed for muscle growth because anabolic hormones (i.e. testosterone, growth hormone and insulin-like growth factor) stimulate muscle protein synthesis and increase muscle size. Kraemer, Noble, Clark, & Culver (1987) demonstrated the dramatic influence of rest periods on blood lactate, hormonal concentrations, and metabolic responses to resistance-exercise protocols in both men and women. In this study the subjects (9 bodybuilders and 8 powerlifters) performed 3-sets of 10-repetion maximum (10RM) for 10-exercises, with 10-seconds rest between sets and 30-to-60 second rest periods between exercises. Blood Lactate values 5-minutes post exercise were over 21 $mmol.L^{-1}$ for both powerlifters and bodybuilders and are among the highest exercise values ever reported (Kraemer, et al., 1987). The mean epinephrine and norepinephrine values observed 5-minute post exercise were greater than previously reported 5-minute post exercise values following maximal (100% VO_2 max) aerobic exercise. Interestingly, there were no significant differences in the values measured between the powerlifters and bodybuilders. Both groups showed significant increases in cortisol suggesting high levels of physiological stress, which was observed more in the powerlifters who had clinical symptoms of dizziness and nausea. The bodybuilders appeared to tolerate this type of exercise protocol better than the powerlifters which may be explained by the different chronic adaptations associated with the respective styles of training used by these two groups of athletes.

Surprisingly, research that has examined the training practices of strength and conditioning coaches and athletes, have not examined what rest periods are used between sets. This may be a limitation to these studies. There is no peer-reviewed information on how long the rest periods are in strongman training, or what the optimal rest periods are for strongman training.

2.5 Training Organisation

2.5.1 Periodisation

Periodisation training is designed to help an athlete peak at the right time. It calls for varying the training stimuli (i.e. training volume, intensity factors, and exercise) over periods of time to allow for a proper progression in the exercise stress and planned periods of rest (Kraemer, et al., 2007). The basic concept of periodisation is that variation in training is needed to optimise both performance and recovery. Strength athletes such as powerlifters and weightlifters may use the classical (linear) periodisation model. The linear model is attributed to the work of the eastern bloc countries in the 1950’s when the weightlifting strength and conditioning coaches found that decreasing the volume and increasing the intensity in the weeks leading towards competition elevated performance (Kraemer, et al., 2007). In the linear model of periodisation (Table 4) each training phase is designed to emphasise a particular adaptation, with the overall goal of providing a consistent increase in stimulus to overload the muscular and neuromuscular systems, resulting in adaptations which will increase overall physical performance (Bompa & Haff, 2009). Performance gains are typically related to changes in more than one physiological system. Training programmes must train each physiological system with specific sport performance goals in mind (Baechle & Earle, 2000).

Table 4: The periodisation of biomotor abilities (Adapted from Bompa & Haff, 2009, p. 138).

<table>
<tr><th></th><th colspan="5">Preparatory</th><th colspan="4">Competitive</th><th>Transition</th></tr>
<tr><td></td><td>General Preparatory</td><td colspan="4">Specific Preparatory</td><td colspan="2">Pre-Competitive</td><td colspan="2">Main Competitions</td><td>Transition</td></tr>
<tr><td>Strength</td><td colspan="2">Anatomical Adaptation</td><td colspan="2">Maximum Strength</td><td colspan="4">Conversion:
-Power
-Muscular Endurance
-Or both</td><td>Maintenance</td><td>Regeneration</td></tr>
<tr><td>Endurance</td><td colspan="3">Aerobic Endurance</td><td colspan="3">Develop the Foundation of Specific Endurance</td><td colspan="3">Specific Endurance</td><td>Aerobic Endurance</td></tr>
<tr><td>Speed</td><td>Aerobic and Anaerobic Endurance</td><td colspan="5">HIT
Anaerobic Power
Anaerobic Endurance
Lactate Tolerance</td><td colspan="3">Specific Speed, Agility, Reaction Time and Speed Endurance</td><td></td></tr>
<tr><td colspan="11">1) HIT = High-intensity training, typically interval-based training that models the sport or activity targeted by the training plan.
2) The training phases are not limited to a specific duration. The focus is the sequence and the proportions between the training phases.</td></tr>
</table>

Stone, O'Bryant, H., & Garhammer (1981) developed a hypothetical model for strength/power sports that had been used by Eastern European weightlifters (Table 5). The model demonstrates the strength progression from hypertrophy to power to peaking. The peaking phase is when the athlete increases their peak strength and power for competition. Bompa (1994) suggested that periodised plans can be used for a number of sports to help athletes' peak at the right time. Studies have shown that classic strength/power periodised training can increase maximal strength (1RM), cycling power, motor performance and jumping ability (O'Bryant, Byrd, & Stone, 1988; Stone, 1981; Stone, et al., 2000; Willoughby, 1992, 1993).

Table 5: Periodisation of training for a strength and power sport (Adapted from Stone et al. 1981).

Mesocycle	1 Hypertrophy	2 Strength	3 Power	4 Peaking	5 Active rest
Sets	3-5	3-5	3-5	1-3	Light physical Activity
Reps	8-20	2-6	2-3	1-3	
Intensity	Low	High	High	Very High	

The past decade has seen the development of more modern forms of periodisation. Non-linear (or undulating) periodisation has replaced the classical, linear approach for some athletes. In nonlinear periodisation the volume and intensity varies greatly within the week. This may suit athletes whose sports are multi-factorial in nature such as the sport of strongman. Strongman competitors need the major components of physical fitness (i.e. strength/power, cardiovascular endurance, and local muscle endurance) to perform well in the variety of strongman events. The use of non-linear periodisation could be more suitable because the constant variations of the acute variables demand constant physiological adaptations to take place (Kraemer, et al., 2007). This could allow the strongman athlete to develop multiple characteristics simultaneously. Currently, it is not known if strongman competitors use periodisation, or what type of periodisation they prefer to use in their resistance training programmes.

The use of periodisation has however been examined in hockey (Ebben, et al., 2004), baseball (Ebben, et al., 2005), football (Ebben & Blackard, 2001) and powerlifting (Swinton, et al., 2009). The NHL and MLB strength and conditioning coaches' practised periodisation (91.3% and 83.4% respectively) compared to only 69% of NFL strength and conditioning coaches. The findings further support that the strength and conditioning coaches in the NFL may be lacking some fundamental knowledge of the scientific principles of resistance training. In contrast, 96.4% of elite powerlifters used periodisation in their training organisation, demonstrating that loading strategies and exercise protocols need to be altered during different stages of training (Swinton, et al., 2009).

2.5.2 Power training methods

The expression of power is critical to successful performance in a majority of sports. Athletes need to be able to express strength quickly, by producing the greatest amount of force in a small amount of time (Chiu, 2007). Because ‘power’ is a product of ‘force and velocity’, both force and velocity must be trained for an athlete to be optimally powerful. Resistance training using explosive movements recruits fast-twitch muscle fibres and trains them to produce large amounts of force in a very short period (Stoppani, 2006). This is because the factor that determines whether to recruit high- or low-threshold motor units is the total amount of force necessary to perform the muscular action (Fleck & Kraemer, 1997). It has generally been believed that powerlifting is inherently a low power activity focused only on maximal force production during slow velocity lifts, and as such may not yield an optimal power training adaptation (Chiu, 2007). However, Escamilla, Lander, & Garhammer (2000b) suggested that the initiation of movement is explosive, but the ensuing movement is at slow velocity due to the high loading and the biomechanics of the lifts involved. Recently, Swinton and colleagues (2009) found that all elite British powerlifters used a load of 31-70% of 1RM as their explosive training load with over half using the load of 61-70% of 1RM for speed repetitions. The results suggest that elite powerlifters become more powerful at any training load, given the intention to move the load as fast as possible. The training practices of elite British powerlifters may be evolving in that they have a good understanding of the scientific principles of resistance training, as the range of loads used are those recommended in literature to maximise power output (Baker, Nance, & Moore, 2001; Kaneko, Fuchimoto, & Toji, 1983; Kawamori, et al., 2005; Thomas, et al., 2007; Thomas, Fiatarone, & Fielding, 1996). However, it is not known what loads are commonly used by non-elite powerlifters and professional and amateur strongman competitors.

Exercises like the jump squat and bench press throw are ballistic exercises which are used to develop explosive power by many athletes (Stoppani, 2006). The advantage of these exercises over the squat or bench press is that the loads can be accelerated through the whole range of motion (there is no deceleration phase). Traditional movements performed explosively with light loads do not create the ideal conditions for the neuromuscular system with regard to explosive strength production. Newton (1996) found that ballistic weight loading conditions in the bench press throw resulted in greater velocity of movement, force output and electromyography (EMG) activity than the traditional bench press performed explosively. The findings suggest that ballistic exercises allow greater overloading on the neuromuscular system, providing greater potential for adaptation. Training at the right load (as a percentage of 1RM) can maximise power output and maximise the potential for adaptation (Cronin, McNair, & Marshall, 2000). The training loads of 20% and 50% of 1RM are suggested for the jump squat and bench press (respectively), as these were the loads found to maximise peak power (Cronin, et al., 2000; Harris, Cronin, & Hopkins, 2007). Peak powers are generally achieved at lighter loads because the velocity of muscle shortening (concentric action) is inversely proportional to the magnitude of the load (Figure 3).

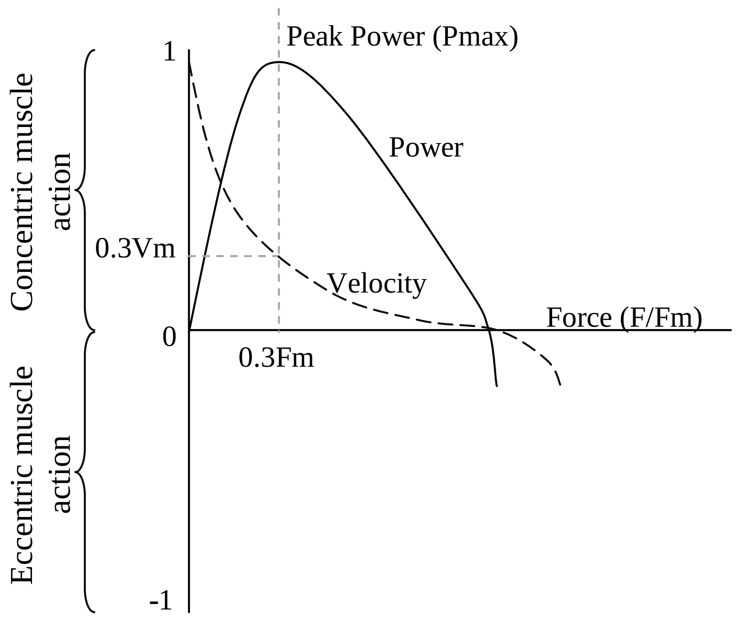

Figure 3: Power production and absorption (solid line) as a function of force and velocity (dashed line) in concentric and eccentric muscle actions. Maximum concentric power (Pmax) occurs at approximately 30% of maximum force (Fm) and velocity (Vm) (Adapted from Baechle & Earle, 2000, p. 474).

Little information exists on the use of ballistic training methods among athletes and sports teams. In a recent study of resistance training practices in elite Spanish club teams (Reverter-Masia, et al., 2009) only 65% incorporated the loaded squat jump into their athletes training, and surprisingly not one of the 77 strength and conditioning coaches incorporated the bench press throw into their athletes training. The results suggest that strength and conditioning of elite Spanish club teams may be lacking knowledge in resistance training practices to elicit optimal adaptations among their athletes. Currently, it is not known if strongman competitors incorporate ballistic exercises in their training regimes.

The use of plyometrics and Olympic lifting has been reported in literature as a means of developing power and whole body explosiveness (Swinton, et al., 2009). Plyometric exercises are based on the utilisation of the stretch-shortening cycle. Plyometrics utilises the stretch-shortening cycle. The stretch shortening cycle combines mechanical and neurophysiological mechanisms and is the basis of all plyometric exercise (Baechle & Earle, 2000). A rapid eccentric muscle action stimulates the stretch reflex and storage of elastic energy thus increasing the force produced during the subsequent concentric action. Plyometric training is thought to increase the sensitivity of muscle spindles, resulting in greater force production. Large differences exist among sports in the use of plyometrics. Over 90% of NHL and MLB strength and conditioning coaches include plyometric exercises for their training (Ebben, et al., 2004; Ebben, et al., 2005), compared to less than 20% of powerlifters (Swinton, et al., 2009). The differences between the sports may indicate sport specificity. Powerlifting is a sport that demands maximal force at lower velocities while hockey and baseball demand movements at high velocities (e.g. sprinting). The sport of strongman involves events where both high forces and high velocities are needed. No research has yet been performed determining if and how strongman competitors incorporate plyometrics in their training programmes.

Olympic lifts (weightlifting) comprise the snatch and the clean and jerk. Olympic lifts are always performed at maximal speed, which may help facilitate greater neural activation and consequently, maximise the rate of force and power development (Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005). The unique biomechanical characteristics of these lifts allow for heavy loads to be moved at high velocities, thus producing higher power outputs than traditional lifts (McBride, et al., 1999). This has made weightlifting one of the most popular ways to develop explosiveness and muscular power.

Studies have examined and compared the effects of different resistance training programmes. McBride and colleagues (1999) reported that athletes participating in weightlifting were significantly stronger than sprinters, and produced significantly higher peak forces, power outputs, velocities and jump heights, in comparison with athletes competing in powerlifting. Tricoli and colleagues (2005) compared the effects of short term heavy resistance training with vertical jump and weightlifting. Interestingly, the weightlifting group improved in all the tests and performed better in the countermovement jump. However, the vertical jump group performed better than the weightlifting group in the half squat test. It is generally believed that performance of the Olympic lifting movements is similar to the joint/muscular recruitment patterns that occur during the performance of many athletic movements. This could be evident in sprinting, jumping and quick changes of direction as they all involve rapid triple extension of ankle, knee and hip. This is further supported by the results of studies that have compared countermovement and non-countermovement jumps to weightlifting performance indices (Canavan, Garrett, & Armstrong, 1996; Garhammer & Gregor, 1992). The studies demonstrate that weightlifting movements are sports specific and seem to be more beneficial for improving performance in strength and power sports that require rapid propulsive forces. One disadvantage to weightlifting movements is they are very complex and require more time for learning than do more traditional exercises. However, the greater skill complexity required for the weightlifting exercises may be advantageous, by facilitating the development of a broader physical abilities spectrum (e.g. balance, coordination, and flexibility), which seems to be better transferred to performance.

Swinton and colleagues (2009) found that over 60% of elite powerlifters used Olympic lifts in their training. This finding demonstrates that despite the differences between powerlifting and weightlifting in regard to movement velocities and lift complexity, powerlifters are aware of the benefits of performing weightlifting exercises and believe that this will transfer well to their sport. Recently, Kawamori and fellow researchers (2005) found that peak power for the power clean was maximised at 70% of 1RM, however no significant differences existed between peak power outputs at 50, 60 80 and 90% of 1RM. Currently, it’s not known if strongman competitors incorporate Olympic lifting in their training regimes or what loading parameters (as a percentage of 1RM) they use in performing Olympic lifts.

The use of Olympic lifting has however been examined among strength and conditioning coaches (Duehring, et al., 2009; Ebben & Blackard, 2001; Ebben, et al., 2004; Ebben, et al., 2005). It was reported that 97.4% of United States high school strength and conditioning coaches prescribed Olympic–style lifts to their athletes (Duehring, et al., 2009). However, a limitation to this study was that of the 128 high school strength and conditioning coaches contacted only 38 responded. Self selection bias may be correlated with traits that affect training prescription making the 29.7% responses rate a non-representative sample. Interestingly, differences exist among strength and conditioning coaches with the prescription of Olympic lifts. Of the 91.3% of NHL strength and conditioning coaches who used periodisation, all incorporated Olympic-style lifts in their athletes training (Ebben, et al., 2004). Similar results were reported for NFL strength and conditioning coaches when 88% reported the use of Olympic-style lifts (Ebben & Blackard, 2001). The results suggest that NHL and NFL strength and conditioning coaches have sound knowledge in the development of strength and power. In contrast to the previous studies, only 23.8% of MLB strength and conditioning coaches reported using Olympic-style lifts in their programmes (Ebben, et al., 2005). The data may suggest that the MLB strength and conditioning coaches either do not believe that Olympic-style lifts are useful for their sport; may believe that it is dangerous or that they do not fully understand the possible benefits of this approach.

2.5.3 Variable Resistance Training

The use of elastic resistance has primarily been used by physiotherapists to help patients regain strength after injury (Page & Ellenbecker, 2005). They are now commonly used in gyms and in strength and conditioning practice for all types of athletes and individuals. The powerlifting community incorporate elastic bands and chains with traditional exercises such as the squat and bench press because it is believed that they are an effective resistance mode to increase maximal strength.

There is growing support for the use of chains (Berning & Adams, 2004; Havelka, 2004; Simmons, 1999) and elastic bands (Baker, 2005; Havelka, 2004; Simmons, 1999; Wallace, Winchester, & McGuigan, 2006) in the resistance training literature. The use of chains and elastic bands has been recommended for multi-joint exercises like the squat that are characterised by an ascending strength curve (Simmons, 1999). The increased training load during the ascent offers the potential for a greater concentric training load than that is manageable because of the mechanical advantage that occurs as the lifter ascends during these exercises (Ebben & Jensen, 2002). As a result, greater muscle tension can be achieved throughout the range of movement thereby improving the potential for neuromuscular adaptations. Interestingly, chains and elastic bands are similar in that they both produce an increase in resistance training load throughout the concentric phase, however they differ in terms of their physical and mechanical properties. These differences affect how the resistance increases; chains increase linearly while the elastic bands increase the load in a curvilinear fashion (McMaster, Cronin, & McGuigan, 2009).

Studies have sought to examine the effects of using chains and bands. Ebben and Jensen (2002) conducted an electromyographic and kinetic analysis of traditional, chain and elastic band squats. Surprisingly, there were no statistically significant differences between the squat conditions and the variables assessed. However, a limitation to the study may have been equating the testing loads. This resulted in the mass of the plates added to the bar for the chain squat during the eccentric and concentric phases being lighter than the non-chain squat. Recently, the effects of combining elastic and free weight resistance on strength and power in athletes, was examined (Anderson, Sforzo, & Sigg, 2008). The subjects who performed seven weeks of elastic and free weight resistance had higher improvements in their back squat (16.47 ± 5.67 kg vs. 6.84 ± 4.42 kg), bench press (6.68 ± 3.41 kg vs. 3.34 ± 2.67 kg), and average power in the countermovement vertical jump (CMVJ) (68.6 ± 84.4 W vs. 23.7 ± 40.6 W) than the subjects who performed free weight resistance alone. These performance enhancements may be due to the altered contractile characteristics associated with combining elastic bands and free weight resistance.

The use of chains and bands may be suitable for power training. Power exercises are exercises that entail acceleration for the full range of movement with resultant high lifting velocities and power outputs (Baker, 2005; Newton, et al., 1996). Adding additional resistance such as chains or bands will allow the athlete to apply high forces much later into the movement, because the bar will slow due to the increasing resistance of the bands or chains, rather than the athlete consciously reducing the push against the barbell (Baker, 2005). This action alters the kinetic profile of the strength exercise to become more like a power exercise (acceleration lasts longer into the range of motion).

Recently, Swinton and colleagues (2009) examined the use of chains and elastic bands in the training practices of elite British powerlifters. Results showed that 57% and 39% of elite British powerlifters used chains and bands respectively. The study shows that elite British powerlifters use advanced training methods that help maximise concentric force potential throughout the entire movement, which may lead to greater strength/power adaptations. However, it is not known if strongman competitors incorporate variable resistance training methods into their training.

2.5.4 Aerobic/anaerobic conditioning

Many sports involve interaction between the aerobic and anaerobic metabolic systems and thus require the performance of both of these forms of training (Baechle & Earle, 2000). However, the contribution of each energy system is determined by sport intensity, duration and rest intervals. For example, in a soccer game energy delivery is dominated by aerobic metabolism, but anaerobic metabolism covers the most decisive actions in the game (i.e. sprints, jumps, tackles) (Wragg, Maxwell, & Doust, 2000). Figure 4 illustrates the relationship between energy delivery systems and exercise duration.

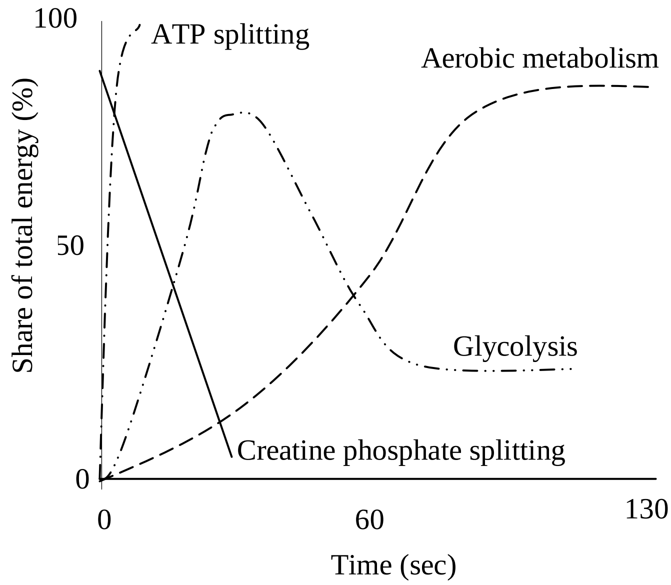

Figure 4: Relationship between energy delivery systems and exercise duration (Adapted from Baechle & Earle, 2000, p. 140)

Understanding the relationship between energy systems and exercise duration is important for strength and conditioning coaches to elicit optimal training adaptations in their athletes. The sports of powerlifting and Olympic weightlifting require a rapid rate of energy to be supplied. They rely more heavily on the phosphagen system as competition and training is short in duration, of very high intensity and involve long rest periods between lifts. In contrast, the sport of bodybuilding relies more heavily on the glycoltic system, due to longer, intense exercise with shorter rest periods. As such, differences exist in muscular adaptations between bodybuilders and the other weightlifting sports. Bodybuilders display a larger number of capillaries per fibre; have a higher percentage of Type I fibres and a lower percentage of fatigable Type II B fibres (Tesch, 1988; Tesch & Larsson, 1982). The results suggest that bodybuilding training is characterised by demands on not only strength but muscular endurance as well. Similar adaptations may exist in strongman competitors where both strength and strength endurance are needed; currently however, the training practices of strongman competitors are not known. Consequently, the muscular adaptations resulting from strongman training have yet to be determined.

Strongman events last from a few seconds (e.g. 1RM log press) to up to 90-120 seconds (e.g. truck pull and medleys) involving high physiological demands both aerobically and anaerobically (Berning, et al., 2007; Keogh, et al., 2010c). Some strongman events would therefore likely involve substantial aerobic metabolism, as the aerobic system resynthesises the anaerobic energy systems. It is highly likely that aerobic and anaerobic training may be needed in strongman training in order for strongman competitors to optimise performance.

Anaerobic training involves a wide range of training methods and modes of exercise. Such details are beyond the scope of this review; therefore, a more cursory overview of anaerobic training will be examined. Sprint work, stair running and plyometrics are just a few of the training activities that can be used for anaerobic exercise protocol. Anaerobic training can be movements that take a fraction of a second (e.g. shot put) to more metabolically demanding activities such as high intensity repeated sprints (Baechle & Earle, 2000). The rest periods during anaerobic work can largely determine training adaptations. If long rest periods are used, lactate acid concentrations are low, increases in stroke volume are minimal and improvements in aerobic power and in the body’s ability to buffer acid are not seen (Baechle & Earle, 2000). Conversely, if short rest periods are used, the opposite adaptations occur, however optimal speed may be compromised due to fatigue and sub-optimal resynthesis of the anaerobic energy systems.

One of the most commonly measured adaptations to aerobic endurance training is an increase in maximal oxygen uptake (VO_2 max) associated with an increase in maximal cardiac output (Baechle & Earle, 2000). VO_2 max is an important factor in determining success in aerobic endurance sports (Astrand & Rodahl, 1986). Aerobic endurance training elicits metabolic adaptations, which include; increased respiratory capacity, lower blood lactate concentrations at a given sub maximal intensity, increased mitochondrial and capillary densities and improved aerobic enzyme activity. However, the intensity of training is one of the most important factors in improving and maintaining aerobic power (Baechle & Earle, 2000). In addition, aerobic endurance training alters body composition by decreasing the relative percentage of body fat with little or no significant effect on fat-free mass (Baechle & Earle, 2000).

A number of tests can be used to measure aerobic and anaerobic fitness. Of the twenty-three NHL strength and conditioning coaches that were surveyed in the study by Ebben et al. (2004), nineteen reported testing for aerobic capacity and seventeen reported measuring anaerobic capacity using some sort of Wingate test. Inbar, Bar-Or, & Skinner (1996) suggest the Wingate anaerobic test is the most 'used test' for anaerobic capacity as it will give accurate results in regard to peak power, mean power, muscle endurance and fatigability. Of the nineteen of the NHL strength and conditioning coaches who reported testing aerobic capacity and cardiovascular endurance most used VO_2 max or combined VO_2 max with lactate testing. In contrast, of the twenty-one MLB strength and conditioning coaches only nine reported testing for anaerobic capacity. Five indicated they used a 300 yard shuttle test, and five reported measuring cardiovascular endurance using the 1.5 or 2 mile run. The findings suggest that NHL strength and conditioning coaches are well informed about testing aerobic and anaerobic fitness, as the VO_2 max test is the 'gold standard' test for measuring aerobic capacity (Armstrong, 2007), and VO_2 max and lactate threshold are two major factors accounting for inter-individual variance in aerobic endurance performance (Hoff & Helgerud, 2004). Currently, it is not known what types of aerobic and anaerobic conditioning strongman competitors do and if they do incorporate aerobic and anaerobic conditioning into their training programmes.

2.6 Strongman Training

The use of functional training techniques have been reported by the United States air force academy strength and conditioning coach (Hedrick, 2003) and NHL strength and conditioning coaches (Ebben, et al., 2004). Hedrick (2003) suggested that using uncommon implements like water filled barrels enhances the need for stability and control, and may reduce injury and improve joint stability. This type of training as seen in strongman training and competitions, may prove more sports specific than conventional gym based training because in most situations athletes encounter dynamic resistance (in the form of an opponent) as compared to a static resistance (Hedrick, 2003). Heavy sled pulls have been proposed to be beneficial for athletes in American football and rugby as these events require very high levels of horizontal total body momentum to be generated in contact situations (Keogh, et al., 2010b). The use of functional training techniques is supported by Kubik (1996) who suggested that incredible levels of strength and muscular development can be achieved by combining common weight training exercises like the squat and deadlift with the lifting of heavy, awkward, hard to manage objects such as beams, barrels, logs, sandbags or kegs. These unique functional training techniques may be one of the reasons that strongman competitors can handle such incredible loads (e.g. 160 kg+ in each hand for the farmers walk).

Very few studies have examined the sport of strongman. Of the studies so far that that have investigated the sport of strongman, the main emphasis has been on the metabolic and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of these exercises (Berning, et al., 2007; Keogh, et al., 2010b; Keogh, et al., 2010c; McGill, et al., 2009). However, the imprecise nature of the overload in strongman training when dealing with large groups of athletes has also gained attention (Baker, 2008). Baker (2008) attempted to develop a mixed training session of strongman exercises such as tyre flipping, log carrying and water filled conduit carrying coupled with some running conditioning. The training session was designed so that the elite rugby league player’s heart rates averaged between 165-175 beats per minute (bpm), in order to replicate the average heart rate (HR) conditions in a game. However due to the different bodyweights and strength levels of the athletes two of the strongest players did not attain the average HR of around 165 bpm. Baker (2008) concluded that for overload to be efficiently applied, loads need to be applied to suit the level for each individual, which may present challenges when dealing with groups of athletes. This result suggests that higher levels of maximal strength and body (muscle) mass may be advantageous in the sport of strongman. However, no research has investigated the determinants of successful strongman performance. The proposed study will give insight into what variables are most beneficial for a number of common strongman events that would appear to have applications to overall conditioning practice. This data could help guide programming and be used by strongman competitors and strength and conditioning coaches in terms of what aspects of performance the athletes should focus on during training.

The first published study of a strongman event, examined the metabolic demands of pushing and pulling a motor vehicle (Berning, et al., 2007). Six male athletes pushed or pulled a 1,960 kg motor vehicle for 400 m. The athletes were experienced with strength training and had a minimum of five years resistance training experience with training sessions involving powerlifting and weightlifting movements. The time to complete the push was 6.0 minutes and pull was 8.2 minutes, but there were no statistical differences in VO_2, heart rate or blood lactate between the pushing and pulling conditions. Interestingly, VO_2 and HR achieved peak values within the first 100 m (65% and 96% (respectively) of treadmill maximum values) and blood lactate (BLa) response from the push and pull reached an average concentration of 15.6 mmol.L^{-1} representing 131% greater than those obtained following a maximal treadmill running test. The subjects were ‘exhausted’ after the event, which may explain the acute decrement suffered in vertical jump height immediately after each of these tasks (mean reduction of 10 cm, -17% of maximum). A criticism of this study is that the distance of 400 m is substantially more than that seen in strongman training and competition; however peak responses (VO_2 and HR) were achieved in the first 100 m suggesting that the strongman car push/pull event, is physiologically demanding for experienced resistance trained athletes.

In a more recent study, Keogh and colleagues (2010c) examined the change in HR and BLa across multiple sets of tyre flips. Five athletes performed two sets of six flips of a 232 kg tyre. Physiological stress was examined using heart rate (HR) and finger-prick blood lactate (BLa) response. Findings from this study showed that the HR and BLa values at the conclusion of the second set were 179 ± 8 bpm and 10.4 ± 1.3 mmol.L^{-1} respectively. Keogh and colleagues (2010c) reported somewhat comparable HR and

BLa levels to that of car push/pull of Berning et al. (2007). The high HR and BLa responses from these studies show that strongman exercises could prove useful in improving anaerobic conditioning and for increasing energy expenditure. However, neither of these two studies examined the metabolic demands of a full strongman training session or the endocrine response to this form of exercise. Crewther and fellow researchers (2006a; 2006b) suggested that the metabolic and endocrine responses to individual training sessions are important determinants of the chronic response in terms of hypertrophy and strength/power adaptation. Future research on strongman could investigate the metabolic and endocrine responses to strongman events; such data could give strength and conditioning coaches and sport scientists some understanding of the acute stresses that strongman training imposes on the system.

Of the biomechanical studies, the first study published was that of McGill et al. (2009). Trunk muscle activation and lumbar spine motion, load, and stiffness were examined in three strongman competitors and comparisons made between the different strongman events e.g. tyre flip, Atlas stones, log lift, farmers walk and yoke walk. These lifts were generally characterised by high-very high spinal compression and shear forces, joint torques and activity of many of the hip and trunk stabilisers (as assessed via EMG). However, differences existed between the lifts in regards to the types of stress and muscle activation. The yoke walk and stone lift produced the highest and lowest spinal joint compression loads (respectively). The keg walk (right shoulder) and tyre flip produced the highest and lowest joint anterior/posterior shear forces (respectively), and the highest and lowest muscular compression loads were produced by the yoke walk and the left hand suitcase carry. The different types of stress and muscle activation from these lifts suggest that core stability is somewhat task-specific. McGill and colleagues (2010) suggested that the core musculature, functions differently than the limb musculature in that the core muscles often co-contract, stiffening the torso such that all muscles become synergists. This could suggest that the core needs to be trained differently than the limb muscles. In addition, core stability training may only lead to significant improvements in functional dynamic performance if the postures, mode and velocity of contraction performed in training, are similar to competitive tasks (Keogh, Aickin, & Oldham, 2010a). Strongman exercises such as the kettle bell and suitcase carry uniquely challenge the lateral musculature (quadratus lumborum and oblique abdominal wall) (McGill, 2010) and may help to strengthen the contralateral hip abductors (Tyson, 2005). Such adaptations may transfer to sports involving sprinting and rapid changes of direction. The study of McGill et al. (2009) showed that strongman events challenge the strength of body linkage, together with the stabilising system, in a different way than traditional gym based resistance training approaches and that loaded carrying would enhance traditional lifting-based strength programmes. High lumbar loads may allow great improvements in core stability; however they may also lead to injury especially if improperly progressed over time and if performed by athletes with insufficient training experience. Injury epidemiology has been examined in powerlifting (Keogh, Hume, & Pearson, 2006), weightlifting (Konig & Biener, 1990) and bodybuilding (Eberhardt, Dzbanski, Fabirkiewicz, Iwanski, & Ronge, 2007) but no such study has been carried out with strongman. As Keogh (2010) reported subtle-moderate differences in the injury epidemiology of powerlifting, weightlifting and bodybuilding, it is likely that strongman training would also have somewhat unique injury risks and epidemiology. Future research is needed to examine the effects of strongman training on spinal loading and the potential injuries that can develop through this type of training. Such knowledge would be beneficial to conditioners and strongman competitors.

The other two biomechanical studies conducted to date have sought to characterise the kinematics of two strongman exercises i.e. the tyre flip and heavy, sprint-style sled pull and to gain some insight into the kinematic determinants of performance of these events (Keogh, et al., 2010b; Keogh, et al., 2010c). Keogh et al. (2010c) performed a temporal analysis of the tyre flip using five resistance trained subjects experienced in the tyre flip. Two sets of six tyre flips were performed with a 232 kg tyre. The duration of each tyre flip and that of the first pull, second pull, transition, and push phases were recorded. Within- and between-subject analyses indicated that the duration of the second pull (i.e. the phase where the tyre moved from just above the knee to the hands-off position prior to the push) was the strongest determinant of tyre flip performance. The heavy sprint-style sled pull was examined using six resistance trained subjects experienced in performing the heavy sled pull (Keogh, et al., 2010b). Video analysis showed kinematic similarities to the acceleration phase of sprinting, however the sled pull had significantly smaller step lengths and step rates, longer ground contact time, and a more horizontal trunk in several phases of these sled pulls. Within- and between-subject analyses of the fastest and slowest trials revealed significant differences in the maximum velocity phase than the acceleration phase. The fastest trials were characterised by significantly greater step lengths, step rates and shorter ground contact times. However, differences in segment/joint angles were less consistent. The findings suggest that the ability to generate large propulsive anterioposterior forces and impulses during relatively short periods of ground contact is critical for successful heavy sled pull performance. The heavy sled pull may be an appropriate mode for training the early stages of the acceleration phase. The greater forward lean required to counteract the heavy load helps to maximise propulsive and minimise breaking forces. This strongman type event may help athletes improve start and acceleration capabilities in sprinting, by increasing power and strength through greater muscle fibre recruitment and neural activation leading to an increase in stride length. In addition, strongman events alike the sprint-style sled/car/truck pull and tyre flip appear quite specific to certain sporting movements (i.e. scrimmaging and breaking tackles in American football or rugby, and cleaning out in rugby etc). The tyre flip and heavy sled pull studies were both successful in obtaining some initial normative kinematic data for these events and in identifying kinematic determinants of performance. Further research is needed to examine the kinetics of these strongman exercises and validate their use in improving performance capabilities. Such data could help guide programming and give support to the use of strongman type exercises in strength and conditioning programmes.

The small amount of strongman scientific literature gives a good indication of what is required for success in this sport. The studies show that the athletes need power through mid-range (Keogh, et al., 2010c), metabolic conditioning (Berning, et al., 2007) and high core and hip abduction strength/stability, grip strength and high levels of overall strength (McGill, et al., 2009). The studies do however have limitations in regard to their small subject numbers. Researchers may find it difficult to recruit larger numbers of subjects due to the relatively small number of strongman competitors and the high physical demands required of subjects in testing.

2.7 Conclusion

The literature demonstrates that understanding resistance-training practices is crucial if such training will result in the optimal performance of athletes. In addition it is clear that elite athletes have more efficient training practices, because they apply scientific principles of resistance training. Information from popular sources suggests that strongman competitors successfully implement novel exercises, power development protocols, heavy resistance materials, and awkward objects such as sandbags and stones in their training. Techniques used in the training and competitions of strongman events could positively transfer to the training programmes of other athletes. Unfortunately, in the scientific literature little information exists on current strongman training practices. The small amount of research performed in this area to date has covered varying aspects of strongman i.e. physiology and biomechanics, but no investigation of training practices has been reported. Therefore the exploratory research aims to examine the training practices of professional and amateur strongmen in order to describe the common, as well as unique training practices employed by these athletes. Results from this study will be invaluable to strength and conditioning coaches, sport scientists and strongman athletes alike.

References for this chapter are included in the list of references collated from the entire thesis at the end of the final chapter.

CHAPTER 3. THE STRENGTH AND CONDITIONING PRACTICES OF STRONGMAN COMPETITORS

3.1 Prelude

Anecdotal evidence suggests that strongman competitors may be some of, if not the strongest men in the world. Elite competitors carry in excess of 160 kg in each hand for the farmers walk and pull planes weighing in excess of 25000 kg. Realising that strongman performance will depend on how these athletes train and the training variables (i.e. loading, sets, reps, specific strongman training) they use, examining their training practices would help develop our understanding of how these competitors train to tolerate the physiological stress accompanied with such high loading. Currently no peer-reviewed literature has examined the training practices of strongman competitors. Therefore the purpose of this study was to examine the strength and conditioning practices of strongman competitors in order to describe the common and unique aspects of how these athletes train. It was thought that analysis of these training variables would allow for a more detailed understanding of the physiological requirements in the sport of strongman. This information will be useful not only for strongman athletes but also for strength and conditioning coaches who may consider using some strongman exercises and training practices in the conditioning programmes of their athletes.

3.2 Introduction

In the past decade the sport of strongman has surged in popularity in many countries, both as a spectator sport and in the number of active competitors. Strongman style training modalities may have some advantages over traditional gym based resistance training approaches. For example, traditional gym based training exercises are generally performed with two feet side by side and require the load to be moved in the vertical plane (Keogh, et al., 2010c). Strongman events represent functional movements in multiple planes and challenge the whole musculoskeletal system in terms of strength, stability, and physiological demands (McGill, et al., 2009). As a result many strength and conditioning specialists are beginning to incorporate strongman exercises into the conditioning programmes of their athletes (Baker, 2008; Hedrick, 2003). While the resistance training practices of strength and conditioning coaches (Duehring, et al., 2009; Ebben & Blackard, 2001; Ebben, et al., 2004; Ebben, et al., 2005) and athletes (Hedrick & Morse, 1988; Katch, et al., 1980; Newsham-West, et al., 2009; Reverter-Masia, et al., 2009; Stanton, et al., 2002; Swinton, et al., 2009; Watanabe, et al., 1992) have been extensively examined, no research has yet examined common strongman training practices. Thus, strength and conditioning coaches have little evidence-base on which to inform the inclusion of strongman training within their programming practice.

Only four scientific studies appear to have been conducted on any of the strongman events (Berning, et al., 2007; Keogh, et al., 2010b; Keogh, et al., 2010c; McGill, et al., 2009) with the emphasis being on the metabolic and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of these exercises. The first published study of a strongman event examined the metabolic demands of pushing and pulling a motor vehicle (Berning, et al., 2007). The athletes achieved peak VO_2 and heart rate (HR) values within the first 100 m (65% and 96% (respectively) of treadmill maximum values), recorded a blood lactate (BLa) concentration of 15.6 mmol.L^{-1} and experienced an acute decrement in vertical jump height of 10 cm (-17% of maximum) immediately after performing each of these tasks. In a more recent study, Keogh and colleagues (2010c) examined the change in HR and BLa across multiple sets of tyre flips. Findings from this study showed comparable HR and BLa levels to that of car push/pull of Berning et al. (2007).

Of the biomechanical studies, the first study published was that of McGill et al. (2009). Trunk muscle activation and lumbar spine motion, load, and stiffness were examined in three strongman competitors and comparisons made in the different strongman events (tyre flip, Atlas stones, log lift, farmers walk and yoke walk). These lifts were generally characterised by high to very high spinal compression and shear forces, joint torques and activity of many of the hip and trunk stabilisers (as assessed via EMG). The other two biomechanical studies conducted have sought to characterise the kinematics of two strongman exercises i.e. the tyre flip and heavy, sprint-style sled pull (Keogh, et al., 2010b; Keogh, et al., 2010c). Keogh and colleagues (2010c) examined the temporal analysis of the tyre flip. The main finding of the study was that the duration of the second pull was the strongest determinant of tyre flip performance. The heavy sprint-style sled pull was examined using six resistance trained subjects experienced in performing the heavy sled pull (Keogh, et al., 2010b). Video analysis showed kinematic similarities to the acceleration phase of sprinting; however the sled pull had significantly smaller step lengths and step rates, longer ground contact time, and a more horizontal trunk in several phases of these sled pulls. The findings suggest that the ability to generate large propulsive anterio-posterior forces and impulses during relatively short periods of ground contact is critical for successful heavy sled pull performance.

The strongman studies provide some evidence of the physiological and biomechanical characteristics of strongman training. The studies show that the athletes need power through mid-range (i.e. the phase where the tyre moved from just above the knee to the hands-off position prior to the push) (Keogh, et al., 2010c), metabolic conditioning (Berning, et al., 2007) and high core and hip abduction strength/stability, grip strength and high levels of overall strength (McGill, et al., 2009). There is no empirical evidence on how strongman competitors train. The purpose of this study was to: a) to describe the strength and conditioning practices employed by strongman competitors and b) to determine how well strongman competitors apply the scientific principles of resistance training. Such an analysis would be most useful for novice strongman competitors and those wishing to compete in the sport of strongman. Strength and conditioning coaches will also benefit in terms of how to best incorporate strongman exercises into their athlete’s resistance training programmes to help maximise performance-enhancements.

3.3 Methods

3.3.1 Experimental approach to the problem

This exploratory descriptive study was designed to provide comprehensive descriptive information about the training practices of strongman competitors. The research hypothesis was that strongmen competitors follow scientifically based strength and conditioning practices in their annual training programmes, which was assessed through a comprehensive survey of strength and conditioning practices.

3.3.2 Subjects

Inclusion criteria were defined as being a local, National and International strongman competitor. Participants had to be males aged 18 to 45 years, have at least twelve months current experience in using common strongman exercises like the tyre flip, farmers walk, log press and sled drags in their conditioning programmes. They had to have competed in at least one strongman competition within the last year or were in-training for their first strongman competition. Only fully completed questionnaires were used for data analysis. Thus, the results from one hundred and sixty-seven strongman competitors from 20 countries were used in the present study. The subjects consisted of 83-local, 65-national and 19-international competitors. Tables 1 and 2 provide a summary of the results. In order to protect the confidentiality of the strongman competitors no participant's details were associated with the survey. The participants mean (±SD) age, height and weight was 30 ± 7 years, 183 ± 7 cm and 113 ± 20 kg, respectively. This study was approved by the AUT University Ethics Committee, Auckland, New Zealand.

3.3.3 Research Instrument

The survey, *Strongman Training Practices* was adapted from the survey used in research with elite powerlifters (Swinton, et al., 2009) (A copy of the survey used with elite powerlifters is presented in Appendix 7). The original survey was pilot tested with participants of the local strongman and powerlifting club to ensure its validity for use with this population. As a result of the pilot testing, the survey was slightly modified including clarifying and improving the wording of a small number of questions before it was administered to the sample. The 65- item strongman survey (Appendix 3) was sectioned into three main different areas of inquiry including, exercise selection, training protocols and organisation, and strongman training. Training protocols and organisation included questions on periodisation, hypertrophy (i.e. training directly focused on building muscle size and mass), maximal strength training, strength and power training (i.e. training methods that were focused on increasing explosive strength and power) and aerobic/anaerobic conditioning. The strongman training section included questions on strongman implements used in training. Participants were asked to give their most common/typical values for each training phase. Closed questions were used for all questions (Questions 1 to 64) except question 65 where an open ended question was presented. Additional demographic information including gender, age, height, weight, weight training and strongman training experience, and 1RM lifts was collected from the questionnaire (Demographic and 1RM information was self reported from participants). Sportsurvey.co.nz was used to launch the electronic survey on the internet.

3.3.4 Data Collection

Strongmen were recruited through multimedia. The primary method was posting the link to the survey on national and international strongman forums (e.g. Aussie Strength forum (Australia), Sugden Barbell forum (United Kingdom), Marunde Muscle (USA), and North American Strongman Incorporated) as well as the social networking site Facebook. Presidents of strongman clubs in New Zealand, Australia and America were contacted by email and sent an electronic link to the online survey to deliver to their club members. An information sheet outlining the objectives and purpose of the study was detailed on the first page of the online survey (Appendix 4).

3.3.5 Statistical Analysis

All questions that were related to the application of the scientific principles of resistance training were categorised. Categorical and ordinal data was reported as percentages of response. Univariate analysis was used to describe the basic features of the data in this study. Microsoft excel was used for data analysis.

3.4 Results

3.4.1 Section 1. Exercise selection

One hundred and sixty seven subjects (100%) reported performing traditional resistance exercises such as the squat and deadlift as part of their training. Subjects were asked to indicate what type of squats and deadlifts they most commonly performed in their training. Sixty-six percent of subjects reported that the back squat was the most commonly performed squat, and 88% reported that the conventional deadlift was the most commonly performed deadlift used in their training. Front squats and partial deadlifts were reported as sometimes and quite often performed by 68% and 63% of subjects respectively. Figures 5 and 6 illustrate the percentages to the various types of squats and deadlifts (respectively) that strongman competitors perform.

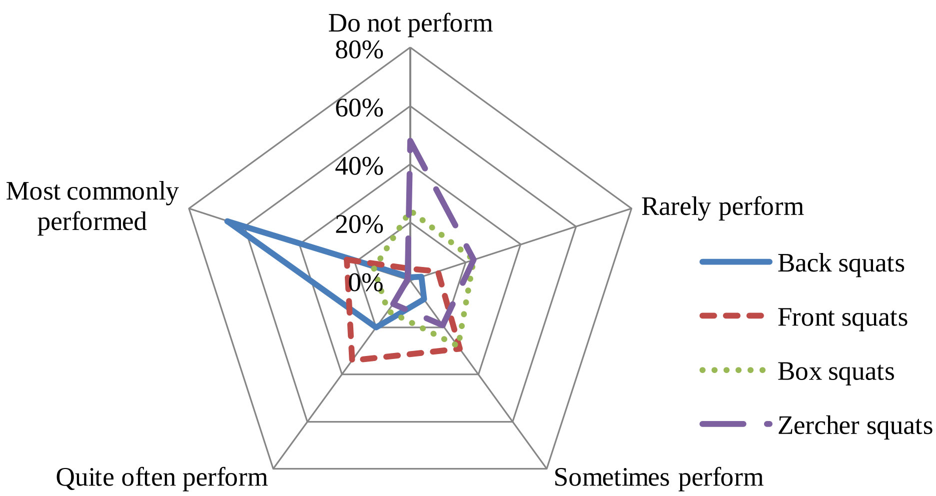

Figure 5: Percentage of strongman competitors and their use of different types of squats.

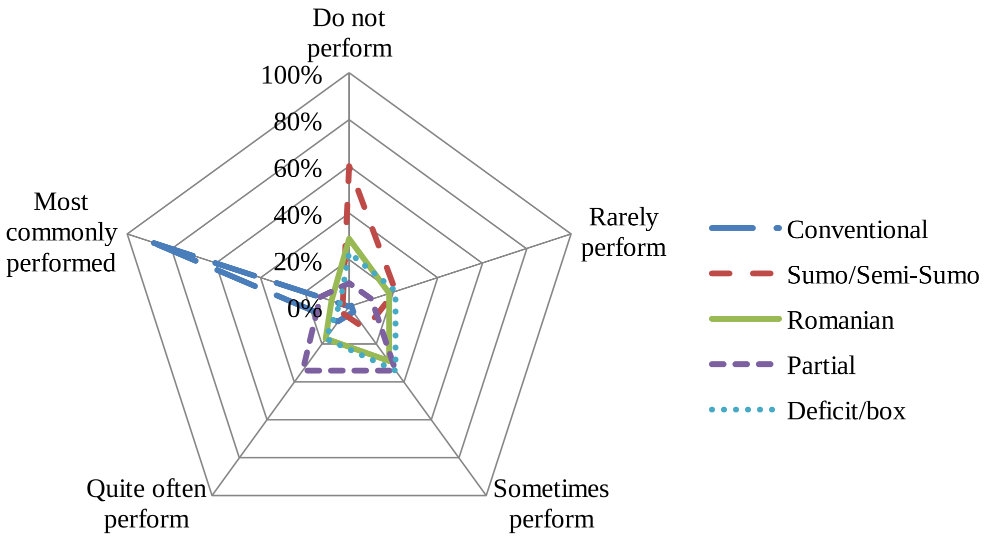

Figure 6: Percentage of strongman competitors and their use of different types of deadlifts.

3.4.2 Section 2. Training Organisation

One hundred and thirty-four of the 167 (80.2%) subjects included some method of periodisation in their training organisation, and one hundred and thirty-eight of the 167 (82.6%) subjects used some sort of training log or training diary.

3.4.2.1 Hypertrophy

One hundred and twenty-three of the 167 (73.7%) subjects included hypertrophy training in their training organisation. Eight-two percent of subjects performed their hypertrophy training close to failure or to failure. Eighty percent of the subjects performed 8 to 12 repetitions per set for their hypertrophy training. Ten repetitions were the most common reported training practice (32.2%) performed for hypertrophy among strongman competitors. Eighty-five percent of the subjects performed 3 to 5 sets per exercise for their hypertrophy training. Fifty-nine percent of the subjects used rest periods of <2 min between sets for their hypertrophy training, with between 1-2 minutes the most common reported rest period (39.7%).

3.4.2.2 Strength

One hundred and sixty-two of the 167 (97.0%) subjects included maximal strength training in their training organisation. Ninety-seven percent of the subjects performed 1 to 6 repetitions per set for their maximal strength training. Three repetitions were the most common reported training practice (46.3%) performed for maximal strength training. Seventy-one percent of the subjects perform 3 to 5 sets per exercise for maximal strength training. Eight-seven percent of the subjects performed rest periods of >2 min between sets for their maximal strength training, with the most common rest period being 3-4 minutes (35.6%).

3.4.2.3 Power

One hundred and fifty-one of the 167 (90.4%) subjects included power training in their training organisation. Eighty-eight percent of the subjects performed 1 to 6 repetitions per set for their power training. Three repetitions were the most common reported training practice (33.8%) performed for power among strongman competitors. Seventy percent of the subjects performed 3 to 5 sets per exercise for their power training. Five sets were the most common reported training practice (31.8%) performed for power among strongman competitors. Fifty-eight percent of the subjects performed rest periods of >2min between sets for their power training. The most common reported rest period between sets (28.5%) among strongman competitors for power training was 2 – 2:59.min.

3.4.2.3.1 Repetition Speed

Subjects were asked whether they performed their traditional resistance exercises as fast as possible (maximum), at speeds less than maximum, or a mixture of maximum and less than maximum. The results showed that 50.6% of strongman competitors performed traditional resistance exercises as fast as possible (maximum), and 40.7% performed a mixture of maximum and less than maximum.

3.4.2.3.2 Explosive Training Load

Subjects were asked whether they attempted to lift submaximal loads (0-70% 1RM) as fast as possible in the squat or deadlift. Approximately 60% of strongman competitors performed speed repetitions with submaximal loads in the squat and deadlift. The submaximal load of 51-60% of 1RM was the most popular training load in the squat

(67.3%) and deadlift (63.1%). Figure 7 illustrates the percentage of strongman competitors who used submaximal loads for each of the power lifts.

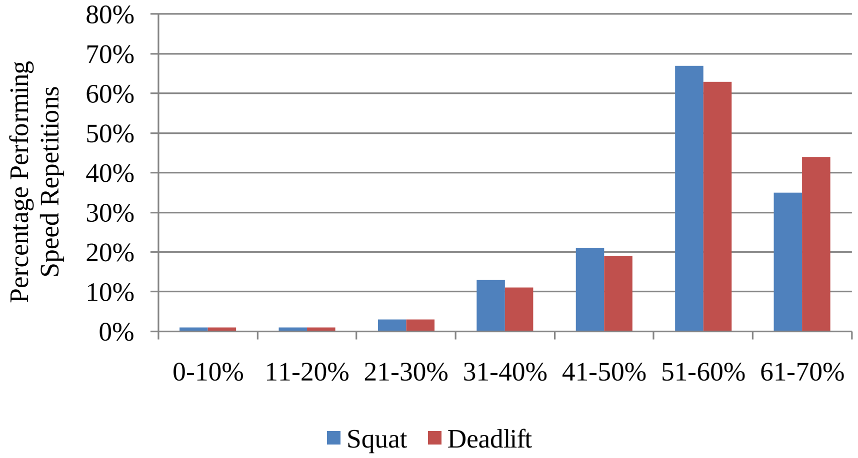

Figure 7: Analysis of submaximal loads (expressed as a percentage of 1RM) used for speed repetitions in the squat and deadlift.

3.4.2.3.3 Resistance Materials Used

Fifty-six percent of the strongman competitors surveyed incorporated elastic bands in their training, and 38% used chains. Figure 8 illustrates the use of bands and chains in the squat, upper body press, deadlift and assistance exercises.

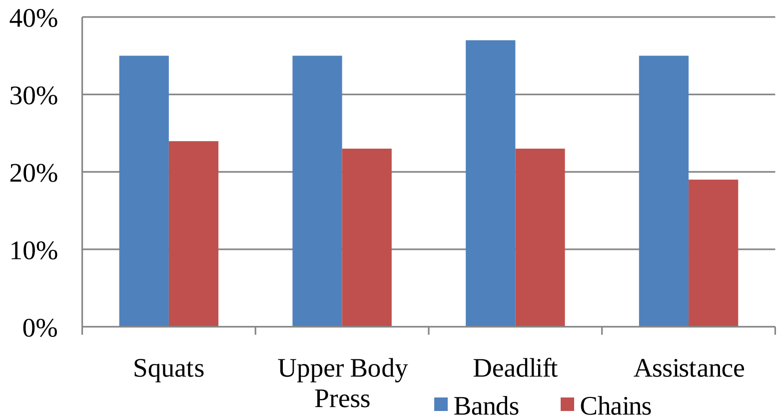

Figure 8: Percentage of strongman competitors who used bands or chains for the squat, upper body press, deadlift, or assistance exercises.

3.4.2.3.4 Adjunct Power Training Methods

Eight-eight percent of the strongman competitors reported that they perform Olympic lifts or their derivatives (cleans, snatch, jerk, and high pull) as part of their strongman training. Subjects were asked to indicate what type of Olympic lifts they performed in their training. Seventy-eight percent of subjects reported that the clean was the most performed Olympic lift used in their training. Figure 9 illustrates the use of the various types of Olympic lifts.

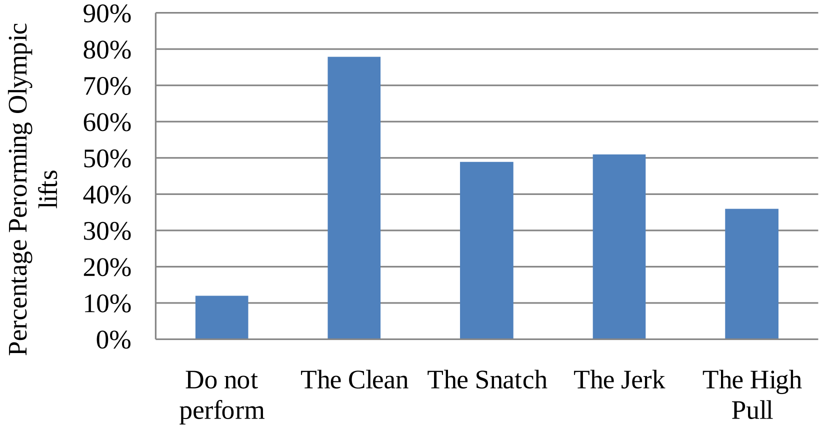

Figure 9: Percentage of strongman competitors who perform Olympic lifting and their derivatives.

Subjects were asked what loads (as a percentage of their maximum) they most typically train with for their Olympic lifting. Thirty-two percent reported using 81-90% of 1RM as their most common Olympic lifting training load. Figure 10 illustrates the loads used for Olympic lifting and their derivatives.

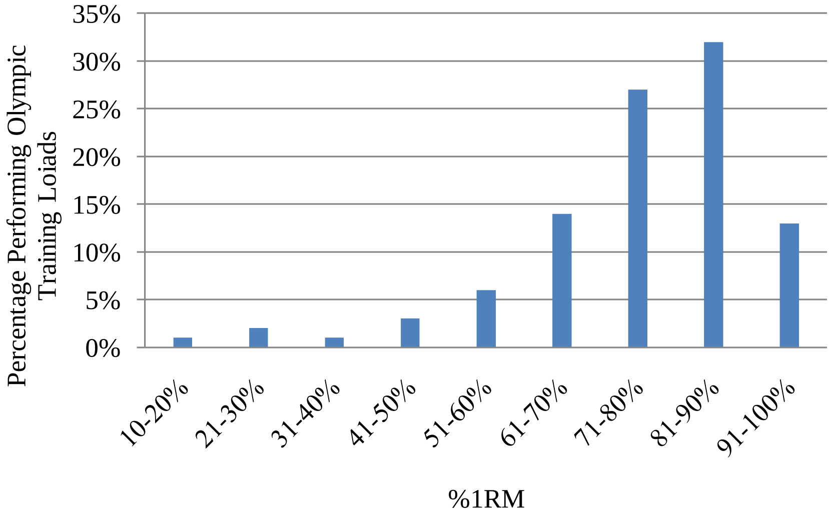

Figure 10: Analysis of loads used for Olympic lifting and their derivatives.

Strongman competitors were asked if they performed upper and lower body plyometrics as part of their training. Twenty-nine percent reported using upper body plyometrics and 54% performed lower body plyometrics.

Twenty percent of the strongman competitors reported that they perform weighted ballistic lifts (i.e. squat jump, bench press throw) as part of their strongman training. Subjects were also asked what loads (as a percentage of their maximum) they most typically train with for their ballistic lifting. Twenty-five percent reported using the training load of 31-40%. Figure 11 illustrates the loads used for ballistic lifting.

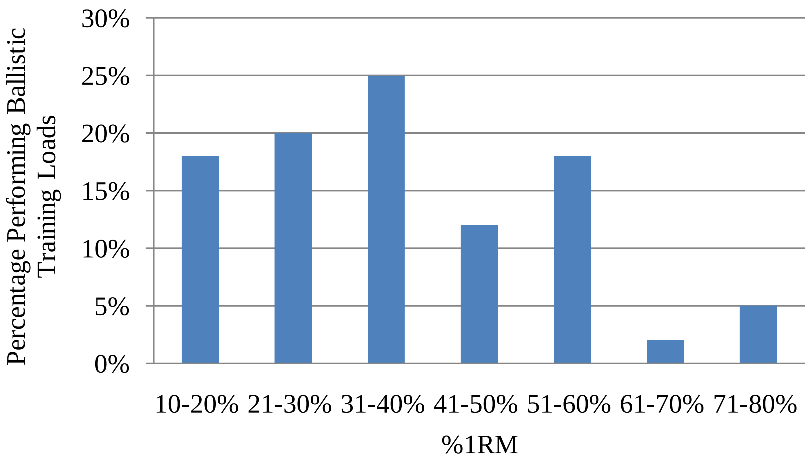

Figure 11: Analysis of loads used for ballistic lifting.

<u>3.4.2.4 Aerobic/anaerobic conditioning</u>

One hundred and fifty subjects (89.8%) reported performing aerobic/anaerobic conditioning as part of their strongman training. Two sessions per week were the most common reported training practice (30.0%) performed for aerobic/anaerobic training among strongman competitors. The time of 16 to 30 minutes were the most common reported training practice (28.5%) performed for aerobic/anaerobic training. Thirty-five percent of subjects reported that other conditioning (i.e. sport specific) was the most commonly performed aerobic/anaerobic conditioning. High intensity interval training, and a combination of high and low intensity cardio were reported as sometimes and quite often performed by 55% and 53% of subjects respectively. Figure 12 illustrates the use of the various types of aerobic/anaerobic conditioning.

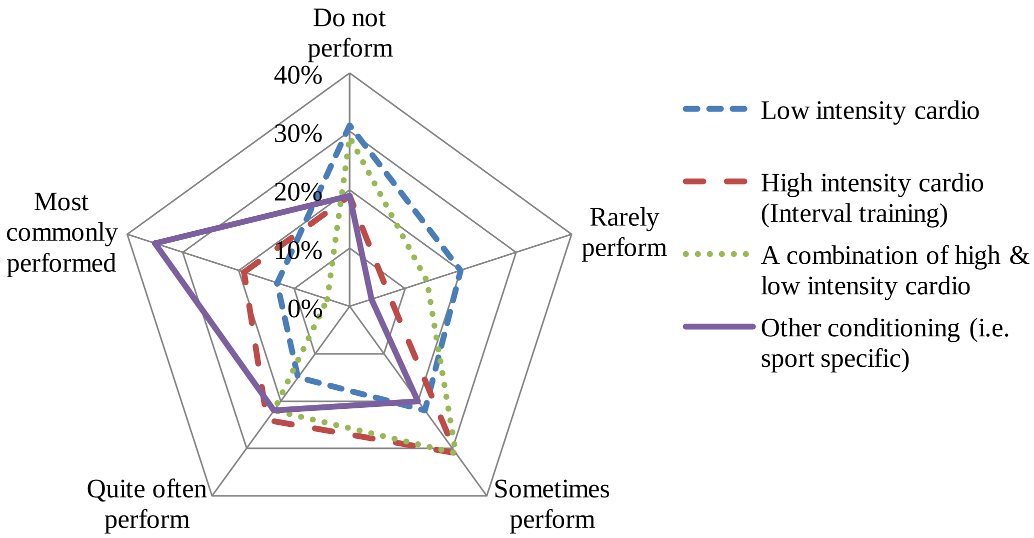

Figure 12: Percentage of strongman competitors who perform aerobic/anaerobic conditioning

Table 6: Summary of most common strength and conditioning practices for exercise selection and training organisation among strongman competitors.

	Percentage that reported using the training practice
Exercise Selection	
Perform traditional resistance exercises	100
Type of squats commonly used in training	
Back squats most commonly performed	65.8
Type of deadlifts commonly used in training	
Conventional deadlift most commonly performed	88.0
Training Organisation	
Periodisation & Planning	
Use periodisation in training organisation	80.2
Use training log or training diary	82.6
Hypertrophy	
Performed hypertrophy training	73.7
Performed hypertrophy training close to failure	63.4
Performed 10 reps for hypertrophy training	32.2
Performed 3 sets per exercise for hypertrophy training	36.0
Use rest periods 1 – 1:59.min for hypertrophy training	39.7
Maximal strength training	
Performed maximal strength training	97.0
Performed 3 reps for maximal strength training	46.3
Performed 3 sets per exercises for maximal strength training	30.0
Use rest periods 3 – 4 min for maximal strength training	35.6
Power	
Performed power training	90.4
Performed 3 reps for power training	33.8
Performed 5 sets for power training	31.8
Use rest periods 2 – 2:59.min for power training	28.5
Performed traditional resistance exercises as fast as possible	50.6
Performed squat as fast as possible (submaximal loads 0-70% 1RM)	59.9
Performed squat as fast as possible with the submaximal load of 51-60% 1RM	67.3
Performed deadlift as fast as possible (submaximal loads 0-70% 1RM)	61.1
Performed deadlift as fast as possible with the submaximal load of 51-60%1RM	63.1
Use bands	56.3
Use chains	37.7
Use Olympic lifts	88.0
Use loads 81-90% for Olympic lifting	31.7
Performed the clean in training	77.8
Performed ballistic lifting (squat jumps & bench press throws)	20.4
Use loads 31-40% for Ballistic lifting	25.0
Performed lower body plyometric drills	53.9
Performed upper body plyometric drills	29.3
Aerobic/Anaerobic conditioning	
Performed aerobic/anaerobic conditioning	89.8
Performed 16-30 min	39.3
Performed sport specific conditioning	35.3

3.4.3 Section 3. Strongman Implement Training

Fifty percent of the strongman competitors surveyed use strongman implements only in a strongman events training day, and 50% mixed gym work & strongman implements together. Forty-four percent of strongman competitors trained with strongman implements once a week, compared to 24% who trained twice a week and 18% who trained <1 a week (may only train once per fortnight).

The farmers walk, log press and stones had the highest percentage of use (96.4%, 95.2% and 94.0% respectively) among the strongman competitors surveyed in this study. Subjects were asked to indicate what other type of strongman implements they used on a frequent basis in their strongman training. Figure 13 illustrates the percentage of strongman competitors that use the various strongman implements in training. Other strongman exercises and implements reported used in training by 37 competitors included; Overhead press (Viking, sleeper press and dumbells), carries (Conan’s wheel, shield, hydrant, and frame), pulls (harness, arm over arm, ropes and chains), walks (duck and yoke), lifts (safe, kettle bells and car deadlift), holds (crucifix), and grip exercises (block, hand and tools).

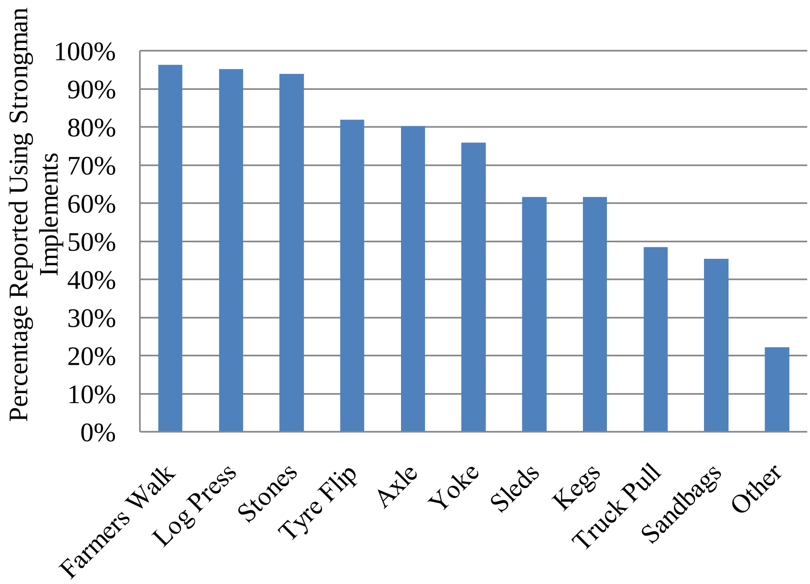

Figure 13: Percentage of strongman competitors that use the strongman implements in training.

3.4.3.1 Tyre flip

One hundred and thirty-seven of the 167 (82.0%) subjects included the tyre flip in their strongman training. Ninety-one percent of those subjects performed the tyre flip once a week or once a fortnight. Less than once a week was the most common reported training practice (53.3%) performed for the tyre flip among strongman competitors. Three sets were the most common reported training practice (40.1%) performed for tyre flip training among strongman competitors. Ninety-one percent of the subjects performed 3 to 10 repetitions per set for their tyre flip training, with 10 repetitions per set being the most commonly (31.4%) performed. The majority of the subjects performed the tyre flip with loads the same as (50.4%) or heavier (34.6%) than those encountered in competition.

3.4.3.2 Log clean and Press

One hundred and fifty-nine of the 167 (95.2%) subjects included the log clean and press in their strongman training. Once a week was the most common reported training practice (61.0%) performed for the log clean and press among strongman competitors. Eight-three percent of the subjects performed 3 to 6 sets for their log clean and press training, with five sets being the most common reported training practice (37.1%). Eight-four percent of the subjects performed 3 to 10 repetitions per set for their log clean and press training, with five repetitions per set being the most common reported training practice (30.4%). The majority of the subjects performed the log clean and press with loads the same as (47.5%) or heavier (39.4 %) than those encountered in a competition involving the log clean and press for repetitions.

3.4.3.3 Stones

One hundred and fifty-seven of the 167 (94.0%) subjects included the stones in their strongman training. Ninety four percent of subjects performed the stones less than once per week or once a week. Once a week was the most common reported training practice (48.4%) performed for the stones among strongman competitors. Ninety-one percent of the subjects performed 1 to 6 sets for their stones training. Three sets were the most common reported training practice (28.0%) performed for stones training among strongman competitors. Ninety-five percent of the subjects performed 1 to 6 repetitions per set for their stones training. Five repetitions per set were the most common reported training practice (29.3%) performed for stones training among strongman competitors.

Sixty-two percent of the subjects performed the stones with loads the same as those encountered in a competition.

3.4.3.4 Farmers Walk

One hundred and sixty-one of the 167 (96.4%) subjects included the farmers walk in their strongman training. Ninety three percent of subjects performed the farmers walk once a fortnight or once a week. Once a week was the most common reported training practice (59.6%) performed for the farmers walk among strongman competitors. Eighty-nine percent of the subjects covered the distance of 20 m to 50 m as part of a working set for their farmers walk training. Twenty meters were the most common reported training practice (37.9%) performed per set for farmers walk training among strongman competitors. The majority of the subjects performed the farmers walk with loads the same (42.3%) as or heavier (46.6%) than those encountered in a competition.

3.4.3.5 Truck Pull

Eighty-one of the 167 (48.5%) subjects included the truck pull in their strongman training. Ninety nine percent of subjects performed the truck pull once a fortnight or once a week. Less than once a week was the most common reported training practice (69.1%) among strongman competitors who performed for the truck pull. Seventy two percent of the subjects covered the distance of 20 m to 30 m as part of a working set for their truck pull training. Thirty meters were the most common reported training practice (39.5%) performed per set for truck pull training among strongman competitors. Eighty-three percent of the subjects performed the truck pull with loads the same (43.0%) as or lighter (40.0%) than those encountered in a competition.

Subjects were asked to indicate how long their rest periods were between sets for their strongman training. Fifty eight percent of subjects rested for >4 minutes between sets.

Table 7: Summary of most common training practices for strongman training.

	Percentage that reported using the training practice
Performed with strongman implements only	50.2
Performed with strongman implements once a week	43.7
Tyre Flip	
Performed the tyre flip	82.0
Performed <1 a week	53.3
Performed 3 sets	40.1
Performed 10 repetitions	31.4
Performed with same load as competition	50.4
Log clean and press	
Performed the log clean and press	95.2
Performed once a week	61.0
Performed 5 sets	37.1
Performed 5 repetitions	30.4
Performed with same load as competition	47.5
Stones	
Performed the stones	94.0
Performed once a week	48.4
Performed 3 sets	28.0
Performed 5 repetitions	29.3
Performed with same load as competition	61.5
Farmers walk	
Performed the farmers walk	96.4
Performed once a week	59.6
Performed a distance of 20 m	37.9
Performed with heavier load than in competition	46.6
Truck pull	
Performed the truck pull	48.5
Performed <1 a week	69.1
Performed a distance of 30 m	39.5
Performed with same load as competition	43.0
Rest period between sets	
Use rest periods >4 minutes	58.1

The last question of the survey was designed to provide the strongman competitors an opportunity to provide additional data or make specific comments regarding the survey. Forty-six strongman competitors offered a variety of responses. These responses are described in Table 8.

Table 8: Higher order theme comments (N=46)*

*In some cases, the participant provided information that represented more than 1 concept and their response contributed to more than 1 higher-order theme.

Higher-order themes	Responses	Select raw data representing responses to this question
Request for a copy of the findings	3	"Please email me a copy".
Enjoyed the survey	2	"Great survey"!
Looking forward to the results	4	"I look forward to reading the final study".
Expression of thanks and/or good luck	9	"Thank you and best of luck".
Contact information provided	4	A specific email address was provided
Concerns about wording of a question	6	"Hard to answer these generic questions". "Reps and sets and loads vary all the time we never do the same thing in a row, and the only constant is change".
Clarification about information provided in the survey	22	"Often sets and reps vary depending on the exercise within a hypertrophy, power and strength session - most common values were given". "Most strongman specific training load varies between lighter, same and heavier than contest loads. Lighter usually mean longer distance for speed (+25 meter. heavier means shorter distance for strength and getting used to heavy loads (10-15 meter)". "For some of the events, sometimes the sets/rep will change depending on if we are working towards a max effort in a contest versus a contest which has a press for reps event".

Miscellaneous	13	“Flexibility and movement athleticism is very important. I'd be interested to note how others also incorporate flexibility training into their programming as well”. “Another good question for stone training would be: how often do you use tacky in your stone training sessions?”

3.5 Discussion

This is the first survey of the strength and conditioning practices of strongman competitors. The number of respondents (167) is higher than the number of respondents associated with surveys of strength and conditioning practices in football, hockey, baseball, basketball and power lifting (Ebben & Blackard, 2001; Ebben, et al., 2004; Ebben, et al., 2005; Simenz, et al., 2005; Swinton, et al., 2009). The majority of strongman competitors use training variables (loads, sets, reps and rest periods) that are within the suggested guidelines for the various phases and types of training investigated in this study, thus supporting the hypothesis that most of the strongmen competitors in this study follow many scientifically based strength and conditioning practices.

The majority of subjects (80.2%) included some method of periodisation in their training organisation, which is lower than that previously reported in elite British powerlifters (96.4%) (Swinton, et al., 2009), but similar to those reported by major league baseball strength coaches (85.7%) and National basketball strength coaches (85.0%). This finding suggests that the majority of strongman competitors design their training to emphasise a particular adaptation with the goal of increasing physical performance.

As all subjects performed traditional gym based resistance exercises, it shows that they understand the need for increasing strength for successful strongman performance. Variants of squats and deadlifts were performed, with back and front squats, and conventional and partial deadlifts the preferred choices of these exercises.

One hundred and twenty-three of the 167 (73.7%) subjects included hypertrophy training in their training organisation. The majority of subjects performed 3 to 5 sets of 8 to 12 repetitions per exercise for hypertrophy training, which is consistent with guidelines for this form of training (Fleck & Kraemer, 2004). Research has established that the force a muscle can exert is related to its cross section area (Komi, 1979). Strongman competitors may use hypertrophy training to increase their fat free mass (FFM), which in turn allows for greater force production (Brechue & Abe, 2002; Keogh, Hume, Pearson, & Mellow, 2009a).

Ninety-seven percent of subjects included maximal strength training in their training organisation. This finding suggests that strongman competitors believe that maximal strength is one of the most important physiological components to compete successfully in strongman events. The majority of subjects performed 3 to 5 sets of 1 to 6 repetitions per exercise with rest periods greater than 2-minutes. These variables are within the suggested guidelines reported for performing maximal strength training (Fleck & Kraemer, 2004). The high levels of maximal strength training may be necessary in the sport of strongman to enable these athletes to cope with the extremely high spinal and hip loads (McGill, et al., 2009).

The results of the present study demonstrate that strongman competitors use a variety of power training methods. The majority of subjects attempted to lift loads in traditional exercises (i.e. squat, bench press and deadlift) as fast as possible. This training practice is commonly referred to as compensatory acceleration and may provide a superior way of training to increase force and and rate of force production (Behm & Sale, 1993; Young & Bilby, 1993). Results from this study demonstrated that 60% of strongman competitors incorporate submaximal loads in the squat and deadlift in their explosive training. This is lower than the 75.0% reported by elite powerlifters (Swinton, et al., 2009). The submaximal load of 51-60%1RM was the most common training load in the squat (67.3%) and deadlift (63.1%) amongst strongman competitors. This finding represents a slightly lower explosive training load than the 61-70%1RM recently reported by elite powerlifters (Swinton, et al., 2009). These differences may be due to the differences between the sports type. In the sport of strongman the ability to move heavy loads at higher velocities would be advantageous. This is evident in the present study with 88% of strongman competitors using Olympic lifting exercises or their derivatives as part of their strongman training, which is higher than the 69% reported by elite powerlifters (Swinton, et al., 2009). This finding gives evidence to the similarities between the training practices of strongman competitors, elite powerlifters and weightlifters. The unique biomechanical characteristics of Olympic lifting exercises allow for the use of heavy loads to be moved at high velocities, thus producing higher power outputs than traditional lifts (McBride, et al., 1999). In addition, the greater skill complexity required for the Olympic lifting exercises may be advantageous by facilitating the development of a broader physical abilities spectrum (i.e. balance, coordination and flexibility) which seems to be better transferred to performance (Hydock, 2001). The findings from this study demonstrate that strongman competitors in common with elite powerlifters combine compensatory acceleration with heavy and submaximal loads to enhance force and rate of force development across a range of velocities.

In the present study 80% of strongman competitors performed their Olympic lifts with loads 51% to 90% of 1RM. Research has found that peak power for the power clean was maximised at 70% of 1RM, however no significant differences existed between peak power outputs at 50, 60, 80 and 90% of 1RM (Kawamori, et al., 2005). In the current study, the clean was the most commonly performed Olympic lifting exercise performed by strongman competitors followed by the jerk, the snatch and the high pull. The clean was also the most frequently performed Olympic lifting exercise among elite powerlifters, however only 10% of elite powerlifters performed the jerk compared to the 52% of strongman competitors. These differences may be due to the specificity of the sports. Strongman competitors may incorporate the jerk in training in order to have a cross over effect to overhead events such as the axle or log clean and press. Stone and colleagues (2007) have suggested that the more similar a training exercise is to actual physical performance, the greater the probabilities of transfer. The results of the present study therefore demonstrate that strongman competitors use a range of Olympic lifting exercises that simulate common competition events and utilise training loads for these exercises that elicit the highest power outputs.

The use of ballistic training and plyometrics have been reported in literature as ways of developing power and whole body explosiveness (Stoppani, 2006; Swinton, et al., 2009). The results of this study indicated that 29% of strongman competitors perform upper body plyometrics and 54% perform lower body plyometrics. This is higher than the 14.3% and 17.9% (respectively) reported by elite powerlifters (Swinton, et al., 2009). The differences between the sports may indicate sport specificity. Plyometric exercises are based on the utilisation of the stretch-shortening cycle. A rapid eccentric muscle action stimulates the stretch reflex and storage of elastic energy thus increasing the force produced during the subsequent concentric action. For strongman competitors training this stretch reflex may be beneficial for events such as the keg toss and log press where higher forces and rate of force production would be advantageous.

In ballistic exercises loads are accelerated through the whole range of motion (there is no deceleration phase). This results in greater velocity of movement, force output and

EMG activity than the traditional exercises performed explosively (Newton, et al., 1996). The results of the present study indicated that only 20% of the strongman competitors perform ballistic lifts (i.e. squat jump, bench press throw) as part of their strongman training. Part of this reason may be sport specificity. Strongman events are generally performed with the intention to move heavy loads as quickly as possible, thus competitors may think it more advantageous training with heavy resistance to improve the high-force portions of the force-velocity curve instead of the high-velocity portion. Of those subjects however who performed ballistic lifting, 93% trained with loads of 10% to 60%1RM. The training loads of 20% and 50% of 1RM have been recommended for the jump squat and bench press (respectively), as these loads were found to maximise peak power (Cronin, et al., 2000; Harris, et al., 2007). The results of the present study indicate that strongman competitors who performed ballistic exercises typically use the training loads that will elicit the highest peak powers.

The results of the current study found that 56% of strongman competitors surveyed incorporated elastic bands in their training, and 38% used chains. Recently, Swinton and colleagues (2009) found that 57.1% of powerlifters incorporated chains and 39.3% incorporated bands (respectively) in their training. It is likely that strongman competitors and powerlifters use chains and bands as a means of developing strength and power. The use of chains and bands are recommended for multi-joint exercises like the squat that are characterised by an ascending strength curve (McMaster, et al., 2009). The increased training load during the ascent offers the potential for a greater concentric training load than that is manageable because of the mechanical advantage that occurs as the lifter ascends during these exercises (Ebben & Jensen, 2002). As a result, greater muscle tension can be achieved throughout the range of movement thereby improving the potential for neuromuscular adaptations.

Strongman events can last from a few seconds (e.g. 1RM log press) to two minutes (e.g. truck pull and medleys) and involve high physiological demands both aerobically and anaerobically (Berning, et al., 2007; Keogh, et al., 2010c). In the present study 89.8% of strongman competitors performed aerobic/anaerobic conditioning as part of their strongman training. Strongman competitors incorporate low and high intensity aerobic/anaerobic conditioning in their programmes, however sport specific conditioning is the most commonly performed (35%). Some clarification of sport specific conditioning was given by some strongman competitors in the open ended question at the end of the survey. When training for sport specific conditioning strongman competitors used lighter than competition loads which allowed a high number of repetitions to be performed for events such as the log clean and press or to help obtain large distances for events such as the farmers walk. The results of the present study demonstrate that strongman competitors incorporate a variety of aerobic and anaerobic training in their strongman training to optimise performance.

The results of the current study found that the majority of strongman competitors trained with strongman implements at least once a week. Fifty percent of the strongman competitors use strongman implements only in a strongman events training day, while the remainder combined gym work & strongman event training in the same session. This finding suggests that strongman utilise two different methods to incorporate event training in their programmes. However, it is unclear if one approach is superior to the other.

The results of the present study demonstrated that strongman competitors use a wide variety of training implements in their training. The farmers walk, log press and stones had the highest percentage of use (96.4%, 95.2% and 94.0% respectively) among the strongman competitors surveyed in this study. Other implements reported as being used by the majority of competitors were the tyre flip, axle, yoke, sleds and kegs. Thirty-seven competitors reported using other implements which consisted of grip strength tools, kettle bells and dumbbells, and carrying, lifting, dragging and pressing implements.

The results from this study demonstrated that the majority of subjects rested for more than 4 minutes between sets for their strongman implement training. Previous research has demonstrated that the rest period between sets and exercises affects the muscles responses to resistance exercise and influence how much of the ATP-PC energy source is recovered (Kraemer, et al., 1991). In addition, the length of the rest period has a dramatic influence on the metabolic, hormonal, and cardiovascular responses to an acute bout of resistance exercise, as well as the performance of subsequent sets (Kraemer, et al., 1987). The rest interval of >4 minutes indicates that strongman competitors use the long rest period to increase their ability to exhibit maximal strength and power with heavy strongman implements. This results indicates that strongman competitors understand the optimal rest periods for strength/power training as the rest interval of >4 minutes is within the suggested guidelines reported for performing absolute strength or power training (Fleck & Kraemer, 2004).

The tyre flip, log clean and press, farmers walk and truck pull are strongman events commonly found in strongman competitions. In the present study 82% percent of competitors reported using the tyre flip, 95.2% included the log clean and press, 96.4% included the farmers walk and 48.5% included the truck pull in their strongman training. Differences existed in the way the subjects trained each event. The majority of subjects trained the tyre flip less than once per week with the most common reported training practice being 3-sets of 10-repetitions with the same load as encountered in competition. Strongman competitors may use the higher rep range for the tyre flip to help with the high physiological demands the tyre flip places on the bodies system (Keogh, et al., 2010c). In contrast the majority of subjects performed the log clean and press once a week with the same loads as encountered in competition. Five sets of 5-repetitions was the most common reported training practice, which has previously been reported as one of the best methods to elicit increases in maximal strength (Stoppani, 2006).

The farmers walk and truck pull were reported as the most common (96.4%) and least used (48.5%) strongman training events (respectively) used by the subjects in this study. The majority of subjects reported performing the farmers walk once a week and the truck pull less than once per week. Differences existed in training practices with the distances and the loads used between these events. The most common reported training practices for the truck pull was pulling a truck for 30 m with loads the same as encountered in competition whereas subjects performed the farmers walk at a distance of 20 m with loads heavier than encountered in competition. This result may indicate that for the farmers walk subjects use the heavier loads to help improve their grip and carrying strength. Observations of elite strongman competitors competing in the farmers walk, gives support to the fact that grip strength and carrying strength may be a fundamental factors in successful farmers walk performance. However, further research is needed to validate this.

Analysis of the answers to the open ended question in the survey revealed that strongman competitors vary their training and periodically alter training variables (i.e. sets, reps, loads) during different stages of their training. The type of events (i.e. max effort or reps event) in a competition can determine loading strategies, and competitors determine the most efficacious training protocols for each event. Future studies should build on this study and examine how strongman training practices differ at various phase of the year.

3.6 Practical Applications

This article serves as the first comprehensive description of common strength and conditioning practices of strongman competitors. Strongman competitors and strength and conditioning coaches can use this data as a review of strength and conditioning practices and as a possible source of new ideas to diversify and improve their training practices. This data should also prove useful to future investigators and practitioners as a source for comparison. Future research should investigate the risks and neuromuscular benefits associated with using strongman type implements in training.

References for this chapter are included in the list of references collated from the entire thesis at the end of the final chapter.

CHAPTER 4. MAXIMAL STRENGTH, ANTHROPOMETRICS AND FUNCTIONAL PERFORMANCE : A REVIEW OF THE LITERATURE

4.1 Prelude

This chapter is the second literature review presented in this thesis. The first literature review explored the theory and application of training practice, and demonstrated the importance of understanding strength and conditioning practices to elicit performance gains in athletes. The review demonstrated the deficiencies in our current knowledge about strongman training practices and established the significance of the exploratory study. The descriptive research described in the previous chapter established that strongman competitors apply the scientific principles of resistance training, and incorporate a variety of strength and conditioning practices that are focused on increasing muscular size, maximal strength and power. It is likely that strongman competitors' strength and anthropometric characteristics may change as a result of resistance training, as changes in strength and anthropometric characteristics as a result of resistance training are well documented. However, what is not known is what types of gym based strength and anthropometric dimensions influence strongman performance. The purpose of this review is to explore the biomechanical factors that are involved in the manifestation of human strength and investigate the relationships between maximal strength (1RM), anthropometrics, and various types of movement performance. An analysis of these variables would help to develop our understanding as to their importance in movement performance.

4.2 Introduction

Maximum strength has generally been defined as ‘the maximal amount of force exerted by a voluntary muscle contraction at a specified velocity’ or the ‘maximum load that can be lifted in one repetition (1RM)’. Power (speed-strength) can be defined as ‘the rate at which mechanical work is performed’ (Power = force x distance/time) and is the product of force and velocity (Power = Force x Velocity). Muscular strength and power are major factors in determining performance across many sporting and athletic events. An example of this would be the research of Pearson, Hume, Cronin and Slyfield (2009), who reported that bench press 1RM and maximum force capability were strongly correlation with forward grinding performance ($r = 0.88$-0.99 and 0.87-0.99, respectively) in eleven elite American Cup sailors.

The one repetition maximum (isoinertial) assessment is widely accepted as the most valid measurement of dynamic strength and is the most common form of strength measurement used most in strength and conditioning practice and research. This type of muscular action simulates the movement patterns encountered in most sporting activities and these types of muscle actions simulate the natural movements of the body, including accelerations, decelerations, and eccentric stretching phases before the concentric or shortening phases (Cronin, McNair, & Marshall, 2003).

Very high levels of maximum strength are required by athletes to compete successfully in the sport of strongman. The very term ‘strongman’ refers to humans displaying feats of strength. Strongman events share many similarities to weight-lifting sports like powerlifting and weightlifting. Differences do however exist in the type of exercises performed. The exercises in weightlifting and powerlifting are bilateral in nature, involve predominantly vertical movement and the production of vertical forces and last only a few seconds in competition (Keogh, et al., 2010c). In contrast, strongman events such as the truck pull and farmers walk can involve both bilateral and unilateral movements in multiple planes, and last from a few seconds to up to two minutes. This makes the sport of strongman more multi-factorial in nature than powerlifting and weightlifting, but high levels of strength and power would still appear to be the primary determinant of strongman performance.

There are several biomechanical factors that are involved in the manifestation of human strength, including neural control, muscle CSA, muscle fibre arrangement, muscle length, joint angle, muscle contraction velocity, joint angular velocity, and body size (Baechle & Earle, 2000). It is widely recognised that the force a muscle can exert is related to its CSA in the muscle. Chronic exposure to resistance training produces marked increases in muscular size and strength that are attributed to a range of neurological and morphological adaptations. An increase in muscular strength without noticeable hypertrophy is the first line of evidence for neural involvement in acquisition of muscular strength. Gabriel, Kamen, & Frost (2006) suggested that early strength gains are associated with an increase of surface electromyographic (SEMG) activity and are related to an increase in motor unit firing rate and possibly motor unit synchronisation.

The primary morphological adaptations as a result of resistance training involve an increase in CSA of the whole muscle and individual muscle fibers. This is due to an increase in myofibrillar size and number (Folland & Williams, 2007). This adaptation permits more actin-myosin cross bridges to be formed during muscle activation, which allows the muscle to produce greater force (Kraemer & Spiering, 2007).

Anthropometric profiling can be used to give an indication of the ability of the muscle to produce force (Keogh, et al., 2009a). A large fat free mass (FFM) reflects a large quantity of skeletal muscle and a greater potential for muscular strength (Brechue & Abe, 2002). One repetition maximum lifts involving the bench press, squat, deadlift and power clean are commonly used by strength and conditioning coaches to assess the strength levels of their athletes. The ability to lift a 1RM load requires the lifter to produce a muscular torque that exceeds the load torque. Torque represents the rotational effect of force, and is the product of that force and the perpendicular distance to its line of action (Hamill & Knutzen, 2009). Therefore, the resultant muscular torque is equal to the sum of the product of the forces and moment arms of each active muscle (Keogh, Hume, Mellow, & Pearson, 2005). The longer the limb segments and hence position of the load, the greater the resistance moment arm and torque and work required to lift the given load. The deterministic model presented in Figure 14 demonstrates the components that determine the amount of weight a lifter can lift.

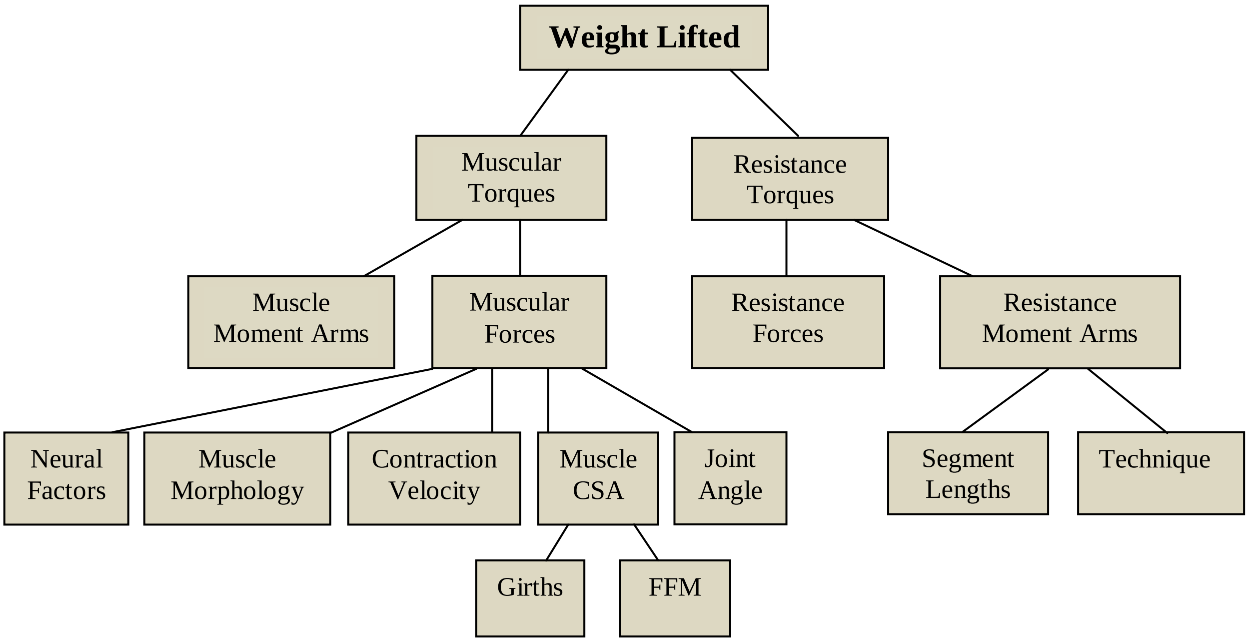

Figure 14: Deterministic model showing the components that affect the amount of weight lifted.

Note: In Figure 14 the term muscle morphology refers to muscle fibre type, muscle fibre arrangement and the elastic properties of muscle, e.g. stretch shortening cycle. Neural factors refer to motor unit recruitment, firing frequency, synchronisation and reflex activity (muscle spindle). Technique is the procedure used to accomplish the specific lift (e.g. squat). FFM and CSA refer to fat free mass and cross sectional area (respectively).

The third class lever is most prominent type of lever arrangement in the human body. This lever has the effort (muscle) force and the resistance force on the same side of the fulcrum (Hamill & Knutzen, 2009). The biomechanical principles for third class levers indicate that the work and torque required to lift a load are proportional to the length of the lever (body segment), therefore the shorter the lever the less work and torque required to lift a load (Keogh, Hume, Pearson, & Mellow, 2007, 2008). In the sport of weightlifting and powerlifting, limb proportions that are advantageous for one lift or part of a lift can be disadvantageous for another. For example, long arms may be beneficial in the deadlift, but may reduce performance in the bench press (Hart, Ward, & Mayhew, 1991; Mayhew, Piper, & Ware, 1993b). Likewise, long arms and trunk may be beneficial in the clean but may reduce performance in the jerk (P. McKenzie (4x Commonwealth games gold medallist), personal communication, April 21, 2010).

Kinanthropometric studies have been conducted on the weight-lifting sports and can play an important role in identifying determinants of performance (Brechue & Abe, 2002; Keogh, et al., 2005; Keogh, et al., 2009a; Keogh, et al., 2009b). The literature demonstrates that anthropometric variables, such as muscle cross sectional area, fat free mass (FFM), and limb segments are all likely to influence strength performance. However, no peer-reviewed literature has examined how anthropometric variables relate to strongman competition performance. The following review examines the influence of anthropometrics and maximal strength on movement performance.

4.3 Anthropometry

Anthropometry has been defined as the science of measurement applied to the human body and generally includes measurement of height, weight, and selected body and limb girths. Body weight and stature (standing height) are the measures of body size, whereas ratios, such as body weight to height are used to represent body proportion (Heyward & Wagner, 2004). To assess the size and proportion of body segments, assessors can use circumferences (using Lufkin tape), skin-fold thickness (using Harpenden skin-fold calipers), skeletal breadths (using a Siber-Hegner GPM anthropometer) and segment lengths (using a Rosscraft segmometer). In addition to measuring body size and proportions, anthropometric measures and advanced bioelectrical impedance machines have been used to assess total body (i.e. body mass, FFM, fat mass and percentage of body fat) and regional body composition (segmented FFM and fat mass).

Anthropometric dimensions can be used to calculate the somatotype of a person. The technique of somatotyping is used to appraise body shape and composition, in which the result gives a quantitative summary of the physique as a unified whole (Norton & Olds, 2004). It is expressed as a three number rating representing endomorphy (the relative fatness), mesomorphy (relative musculo-skeletal robustness) and ectomorphy (slenderness of a physique) respectively (Norton & Olds, 2004). Anthropometric profiling and somatotyping can be used to evaluate the level of body fat in both athletes and other members in the general community. Anthropometric indices such as BMI, waist to hip ratio (WHR), waist circumference and sagittal abdominal diameter are commonly used in the general community to identify individuals at risk for disease (Heyward & Wagner, 2004).

Large differences in percentages of body fat and lean body mass have been reported among athletes across a range of sports (Barr, McCarger, & Crawford, 1994). For athletes whose sports involve weight classes such as wrestling, weightlifting and powerlifting, monitoring body composition can be especially important. As mentioned previously, a larger FFM may be more beneficial for muscle force production which could therefore optimise sports performance. Therefore weightlifters and powerlifters may wish to increase their FFM and decrease their body fat percentage in order to increase performance and stay in their current weight class.

4.4 Anthropometric Characteristics

The anthropometric characteristics of strongman competitors have not been investigated. Anthropometric characteristics have however been investigated in the other weight-lifting sports (Brechue & Abe, 2002; Fry, et al., 2006; Katch, et al., 1980; Keogh, et al., 2007, 2008; Keogh, et al., 2009a). Studies have shown that the anthropometric proportions of the three categories of weight-trained athletes (powerlifters, weightlifters and bodybuilders) are considered abnormally large compared with the proportions of Behnke’s reference man (Katch, et al., 1980). This is not surprising as it is generally known and accepted that heavy resistance training produces increases in muscle mass. However, proportional differences exist between the three groups of weight-trained athletes. Bodybuilders were found to have greater hypertrophy in their chest, biceps and forearms (Katch, et al., 1980), and thighs (Huygens, et al., 2002) than weightlifters and powerlifters. Borms, Ross, Duquet, & Carter (1984) suggested that bodybuilders are extreme mesomorphs (regardless of weight class), more so than any other group of athletes. This may be due to the different types of training and the differences between the weightlifting sports. Bodybuilding is a sport that is judged on the physical appearance of an athlete rather than the weight lifted in competition (Keogh, 2010). The bodybuilders’ objectives are to develop lean body mass, symmetry, definition and good posing presentation. In contrast, the sports of weightlifting (i.e. the snatch, and the clean and jerk) and powerlifting (i.e. squat, bench press and deadlift) require the athletes’ to lift as much load as they can for one repetition in a variety of lifts. A summary of the anthropometric characteristics of these three groups of athletes are presented in Appendix 8.

Current men's lifting records reveal that male weightlifters in the lightweight bodyweight (body mass) classes can lift three times their bodyweight in the clean and jerk, and powerlifters can lift over five times their body mass in the squat and deadlift. Although these weight-lifting activities require a combination of muscular strength, muscular power, flexibility, kinaesthetic awareness and lifting technique (Kraemer & Koziris, 1994), these impressive displays of strength appear to be related to the lifters anthropometric characteristics (Brechue & Abe, 2002; Fry, et al., 2006; Mayhew, McCormick, Piper, Kurth, & Arnold, 1993a). In particular, weightlifters and powerlifters are generally of average to below average height, are highly mesomorphic, possess high body and fat-free mass per unit height, and have large trunk and limb girths (Brechue & Abe, 2002; Katch, et al., 1980; Mayhew, et al., 1993a).

The greatest anthropometric determinant of maximal strength is most likely fat free muscle mass. Therefore, athletes competing in weight class categories would want the greatest proportion of their body mass to be useful muscle rather than fat mass (Brechue & Abe, 2002; Mayhew, et al., 1993a). Athletes do however need to be careful in regard to trying to shed fat if they are already near essential fat levels (~ 6% in males) as FFM can be lost which will be detrimental to performance (Withers, et al., 1997). Therefore, essential fat levels should not be viewed as ideal or target fat levels for athletes (Fleck & Kraemer, 2004). Powerlifters and weightlifters also possess relatively large bony breadths/bone mass (Katch, et al., 1980; Keogh, et al., 2007; Marchocka & Smuk, 1984). This may be due to the high physiological stresses (mechanical loading) associated with weight-lifting exercises. These high stresses exceed the threshold stimulus that initiates bone formation. As such, osteoblasts lay down additional collagen fibres at the site of the stress formation and become mineralised, which increases the bone diameter (Baechle & Earle, 2000) and bone mineral density (Dickermann, Pertusi, & Smith, 2000). As a result, the powerlifters and weightlifters get heavy skeletal structures (Keogh, et al., 2007, 2008) which may help to contribute to their ability to accumulate large amounts of muscle mass (Mayhew, et al., 1993a; Mayhew, et al., 1993b) and withstand the tremendous compressive and shear forces that occur when performing these activities (Escamilla, et al., 2000b). Such a view is supported by

(Tsuzuku, Ikegami, & Yabe, 1998) who found, high correlations (r = 0.79) have been reported among powerlifters between strength and bone density.

Certain anthropometric characteristics have been found that distinguish stronger powerlifters from weaker powerlifters (Keogh, et al., 2009a). Recently, Keogh and colleagues (2009a) examined the anthropometric profiles of 17-weaker and 17-stronger Australasian and Pacific powerlifters. The only significant differences between the two groups were muscle mass (38.0 ± 4.8 vs 42.0 ± 6.7 kg), flexed upper arm girth (38.8 ± 3.4 vs 43.1 ± 4.6 cm) and stronger lifters had significantly shorter lower leg length than weaker lifters. Both groups exhibited a relatively similar overall anthropometric profile; however stronger lifters had moderately greater flexed upper arm, forearm, chest and limb girths than the weaker lifters.

4.5 Anthropometric and 1RM variables

Studies have sought to determine the relationship and predictability of anthropometric variables to 1RM strength performance in males and females. A summary of these studies is presented in Table 9. Anthropometric dimensions have been used to predict 1RM bench press in 113 untrained females (Scanlan, Ballmann, Mayhew, & Lantz, 1999). Anthropometric measures including arm CSA, flexed arm circumference, mesomorphy, and forearm circumference were found to have only moderate correlations (r = 0.42-0.45) with bench press strength. Further, the multiple regression analysis (r^2 = 0.41), determined that prediction of bench press strength from anthropometric dimensions was not accurate or practical using untrained females. In contrast, studies that sought to determine the relationship and predictability of anthropometric variables to 1RM strength performance in trained female athletes, produced significant multiple correlations (Mayhew & Hafertepe, 1996; Peterson, et al., 1996). Arm CSA and %fat produced a significant multiple correlation (r^2 = 0.75) for predicting bench press (Peterson, et al., 1996) and a significant multiple correlation (r^2 = 0.67) was reported between thigh circumference and total leg length with 1RM leg press strength (Mayhew & Hafertepe, 1996). The studies may demonstrate that 1RM strength tests may be best used with experienced trained athletes due to the improved recruitment and activation of the involved muscles that result over time from consistent resistance training. Furthermore, experienced trained athletes may have substantially reduced the neural inhibition controlling the amount of muscular force produced

(Rutherford & Jones, 1986), and may provide a better population for determining the degree to which anthropometrics influence strength performance.

The study of Mayhew et al. (1993b) supports this view. Mayhew and colleagues (1993b) examined anthropometric dimensions and 1RM strength performance (bench press, squat and deadlift) in 58 resistance trained college football players following the completion of a 10-week resistance training programme. Large ($r = 0.54$-0.79) correlations were reported for arm circumference, arm muscle cross sectional area, thigh circumference, lean body mass and lifting performance, and multiple regression analysis selected arm size and %fat as variables common to all three lifts. The anthropometric variables that were entered into the regression analyses to predict bench press, squat and deadlift strength, accounted for 75.7%, 54.5% and 44.9% (respectively) of the total variance, demonstrating that prediction of bench press from anthropometric dimensions could be accurate and practical using trained males.

The use of anthropometric variables to predict bench press and squat strength was also examined in forty-two male powerlifters (Keogh, et al., 2005). The anthropometric variables that were most highly correlated to bench press and squat strength were those related to FFM, muscular girths and somatotype. In contrast, limb length, limb length ratios and bony breadths were typically not related to bench press or squat strength. The lack of any significant correlation between strength and limb lengths/limb length ratios is in contrast to the study by Mayhew et al. (1993b) for squat strength. However, the significant leg length ratio correlations reported in Mayhew et al. (1993b) study were not calculated in the study by Keogh et al. (2005). The anthropometric variables selected for analysis to predict bench press and squat in the study by Keogh et al. (2005) were flexed upper arm girth and arm length/height index, and musculoskeletal size. The bench press and squat accounted for 71% and 49% (respectively) of the total variance, suggesting that anthropometric variables could be used to predict bench press and squat strength with moderate accuracy. Interestingly, the studies of Mayhew et al. (1993b) and Keogh et al. (2005) both found the ability of the anthropometric variables to predict strength were greater in the bench press than the squat and deadlift exercises. These differences may be due to the amount of muscles recruited, morphological differences, core stability, technique variation and the complexity of the squat and deadlift compared to bench press. The studies demonstrate that significant relationships exist between anthropometric dimensions and 1RM strength performance, and prediction of 1RM strength tests from anthropometric dimensions could be an accurate and practical measure providing trained subjects are used. However, the predictability of anthropometric variables decreases as strength test complexity increases. No study has yet related anthropometric dimensions to 1RM strength performance in strongman.

Table 9: Anthropometric correlates and predictors of 1RM strength performance in males and females.

Study	Subjects	Anthropometric measures	Strength Measures			Predictor equations
			Bench press	Squat	Deadlift	
Mayhew et al. (1989)	242 moderately trained females	Height	0.04			**1.** Bench press (kg) = (0.257 x Upper arm CSA (cm^2)) + (0.261 x Chest girth (cm)) + (0.095 x Shoulder/hips x 100) - 8.88 (r= 0.58, r^2= 0.34, SEE= 5.1)
		Body mass	0.42**			
		FFM	0.42**			
		Body fat %	0.24**			
		Upper arm girth	0.49**			**2.** Bench press (kg) = (0.959 x Upper arm girth (cm)) - (0.376 x Triceps SKF (mm)) + (0.240 x Chest girth (cm)) – 4.21 (r= 0.58, r^2= 0.34, SEE= 5.1)
		Arm CSA	0.53**			
		Chest girth	0.49**			
		Upper arm length	-0.04			
		Lower arm length	.02			
Hart et al. (1991)	54 male University students	Height	0.21			
		Body mass	0.67**			
		FFM	0.64**			Bench press (kg) = (0.66 x Upper arm CSA (cm^2)) - (2.06 x age) – (2.92 x Upper arm length (cm)) + (1.15x lean body mass (kg) + 127.6 (r= 0.79, r^2= 0.62, SEE= 13.8)
		Body fat %	0.37**			
		Upper arm girth	0.46**			
		Upper arm CSA	0.73**			
		Chest girth	0.69**			
		Upper arm length	-0.05			
		Lower arm length	0.12			
Mayhew et al. (1991)	170 college males	Height	0.22**			**1.** Bench press (kg) = (0.71 x Upper arm CSA (cm^2)) + (1.12 x chest girth) – (0.50 x %fat) – 71.6 (r^2= 0.69, SEE= 11.6)
		Body mass	0.68**			
		FFM	0.73**			
		Body fat %	0.29**			**2.** Bench press (kg) = (3.28 x Upper arm girth (cm)) + (1.18 x chest girth) – (1.20 x %fat) – 125.6 (r^2= 0.67, SEE= 11.8)
		Upper arm girth	0.77**			
		Upper arm CSA	0.79**			
		Chest girth	0.72**			
		Upper arm length	0.13			
		Lower arm length	0.20**			

Mayhew et al. (1993a)	99 high school males	Height	0.47*		0.55*	**1.** Bench press - Five significant variables accounted for 68.9% of explained variance. Body mass (70.7%), 6SKF (14.4%), forearm length (6.3%), arm CSA (5.1%) and age (3.5%)
		Body mass	0.73*		0.65*	
		6SKF	0.45*		0.39*	
		Chest girth	0.70*		0.65*	
		Arm girth	0.70*		0.70*	**2.** Deadlift - Four significant variables accounted for 62.4% of explained variance. Body mass (71.2%), 6SKF (16.9%), thigh girth (6.7%), and age (5.2%)
		Thigh girth	0.61*		0.61*	
		Calf girth	0.55*		0.51*	
		Leg length	0.24		0.39*	
Mayhew et al. (1993b)	58 college football players	Height	0.19	0.08	0.13	**1.** Bench press (kg) = (0.96 x Arm CSA (cm^2)) + (3.08 x BMI) – (2.71 x %fat) – 128.7. (r^2 = 0.76, SEE = 12.1)
		Body mass	0.53*	0.50*	0.50*	
		FFM	0.68*	0.60*	0.54*	**2.** Squat (kg) = (1.27 x Arm CSA (cm^2)) – (10.13 x Leg ratio) – 1.55 x Body fat %) + 442.80. (r^2 = 0.55, SEE = 23.9)
		Body fat %	0.16	0.22	0.29*	
		Arm girth	0.71*	0.61*	0.61*	
		Arm CSA	0.79*	0.64*	0.59*	**3.** Deadlift (kg) = (5.09 x Arm girth (cm)) – (2.16 x Body fat %) + (2.01 x Thigh girth (cm)) – 97.67. (r^2= 0.45, SEE= 23.1)
		Thigh girth	0.54*	0.54*	0.56*	
		Calf girth	0.37*	0.37*	0.35*	
		Leg length	0.01	-0.19	-0.02	
Mayhew et al. (1993c)	72 college football players	Height	0.11	0.09	0.16	**1.** Bench press (kg) = (3.27 x Arm girth (cm)) - (3.74 x Arm length) + (1.59 x FFM) – (2.30 x Body fat %) – (1.04 x drop distance (cm)) + 95.9 (r^2 = 0.69, SEE = 13.2)
		Body mass	0.55**	0.48**	0.45**	
		FFM	0.61**	0.54**	0.52**	
		Body fat %	0.21	0.15	0.10	**2.** Squat (kg) = (4.39 x Age (yrs)) + (2.54 x Arm girth (cm)) – (4.48 x Body fat %) + (7.38 x BMI (kg/m^2) – 175.6. (r^2= 0.55, SEE= 18.4)
		Arm girth	0.71**	0.64**	0.56**	
		Chest girth	0.38**	0.37**	-0.49**	
		Arm length	-0.10	-0.08	0.09	
		Leg length	-0.03	-0.08	-0.07	**3.** Deadlift (kg) = (1.98 x Arm girth (cm)) + (0.48 x Chest girth (cm)) + (1.17 x FFM) – (2.86 x Body fat %) + 7.1. (r^2= 0.45, SEE= 18.4)

Peterson et al. (1996)	34 college female athletes	Arm CSA	0.70#			Bench press (kg) = 18.0 + (0.97 x Arm CSA (cm^2) - %fat. (r^2= 0.75, SEE= 6.5)
		Forearm girth	0.66#			
		FFM	0.63#			
		Arm girth	0.60#			
		Chest girth	0.59#			
Scanlan et al. (1999)	113 untrained college females	Height	-0.07			**1.** Bench press (kg) = (2.43 x Muscle factor) + (1.13 x length factor) + 28.6 (r^2= 0.34, SEE= 5.6)
		Body mass	0.35**			**2.** Bench press (kg) = (0.77 x Arm girth (cm)) – (0.27x Hip girth (cm)) – (0.58 x Hip DIA (cm)) – (0.44 x Subscapular SKF (mm)) – (0.33 x Calf SKF (mm)) – (0.29 x Height (cm)) + (0.56 x Weight (kg)) + 77.4 (r^2= 0.41, SEE= 5.4, CV= 18.9%)
		FFM	0.36**			
		Body fat %	0.19			
		Arm girth	0.45**			
		Chest girth	0.36**			
		Calf girth	0.27**			
		Arm length	-0.06			
Brechue and Abe (2002)	20 elite male powerlifters	FFM	0.88**	0.94**	0.86**	**1.** Bench press (kg) = 28.1 + (2.20 x FFM)
		FFM/Height	0.87**	0.95**	0.87**	**2.** Squat (kg) = 53.8 + (3.13 x FFM)
		Biceps thickness	0.77**	0.85**	0.84**	**3.** Deadlift (kg) = 138.9 + (1.92 x FFM)
		Forearm thickness	0.82**	0.89**	0.89**	
		Chest thickness	0.77**	0.84**	0.83**	
		Quadriceps thickness	0.67**	0.82**	0.79**	
		Hamstring thickness	0.69**	0.83**	0.77**	
		Calf thickness	0.78**	0.88**	0.83**	

Keogh et al. (2005)	42 male powerlifters	Height	0.12	0.07	**1.** Bench press (kg) = (7.05 x Flexed upper arm girth) – (3.92 x Arm length-height index) + 38.4. (r^2= 0.71, SEE= 19.7kg, CV= 14%). **2.** Squat (kg) = (535.76 x Musculoskeletal size) – 21.44. (r^2= 0.49, SEE= 36.4kg, CV= 17%).
		Body mass	0.49**	0.61**	
		Body fat	0.41**	0.49**	
		FFM	0.55**	0.64**	
		Musculoskeletal size	0.55**	0.68**	
		Chest girth	0.63**	0.61**	
		Flexed upper arm girth	0.71**	0.72**	
		Mid thigh girth	0.52**	0.59**	
		Total arm length	-0.06	0.05	
		Thigh length	-0.07	0.08	
			Leg press		
Mayhew & Hafertepe (1996)	15 female high school track athletes	Height	-0.44		Leg Press (kg) = (424.8 + 2.2 x Thigh girth (cm)) - (4.2 x Total Leg Length (cm)) (r^2= 0.67, SEE= 20.2kg)
		Body mass	0.16		
		Thigh girth	0.42		
		Total leg length	-0.63*		
		Thigh length	-0.50		

**Correlation is significant P ≤ 0.01, * Correlation is significant P ≤ 0.05, # Significance not stated in abstract.
Key: SKF - Skinfolds, FFM - Fat free mass, CSA - Cross sectional area, % - Percentage, SEE - Standard error of the mean, CV - Coefficient of variation.

4.6 Anthropometric dimensions, strength variables and performance

Currently, no studies have sought to determine if anthropometric dimensions and strength variables can predict strongman performance. However, such studies have been conducted in other sports and in various types of movement tasks (Keogh, 1999b; Kukolj, Ropret, Ugarkovic, & Jaric, 1999; Mayhew, et al., 2004; Ugarkovic, Matavulj, Kukolj, & Jaric, 2002; Weiss, Relyea, Ashley, & Propst, 1997; Williams & Wilkinson, 2007; Zampagni, et al., 2008). The rationale behind this is that if anthropometric variables and strength variables could predict performance, such data could then guide talent identification and strength and conditioning practice.

It was mentioned previously that limb proportions that could be advantageous for one of the powerlifts can be disadvantageous for another. Mayhew, Ball, Ward, Hart, & Arnold (1991) suggested that individuals with short arms and a large chest circumference may have a decided advantage when attempting a 1RM while performing the bench press. As such, researchers have examined the use of anthropometric dimensions to try and enhance the predictability of the NFL-225 test (Hetzler, Schroeder, Wages, Stickley, & Kimura, 2010; Mayhew, et al., 2004). The NFL-225 test is a test in which subjects perform the bench press to failure with a load of 225 lbs (~100 kg) and the 1RM predicted from the amount of repetitions performed. Mayhew and colleagues (2004) reported that none of the anthropometric variables (percent fat, lean body mass, and arm cross-sectional area) could make a significant additional contribution to repetitions-to-fatigue (RTF) from the NFL-225 for predicting 1RM. In contrast, Hetzler and colleagues (2010) found that with the addition of the anthropometric variables (arm circumference and arm length) the regression equation for the NFL-225 test improved from R^2=0.87 to R^2=0.90. The small improvement in the regression equation may be due to the subjects used in the study. Hetzler and colleagues (2010) used 87-National Collegiate Athletic Association (NCAA) division IA players while Mayhew et al. (2004) used 61-NCAA division II players. Differences in skill levels and strength training experience could have been factors that influenced results. This was apparent with NCAA division IA players having larger arm CSA and higher 225 lb bench press scores than NCAA division II players.

Stone lifting is one of the most popular strongman events and is usually the last event held at strongman competitions. Unfortunately, no study has investigated the determinants of stone lifting performance, however simple anthropometric and physical performance tests have been conducted to predict maximal box-lifting ability in 29 physically active adults (Williams & Wilkinson, 2007). The study found that a good prediction of 1.4 m box lifting performance (95% of the variation could be accounted for) was obtained from a regression equation that included the variables body mass, body composition and upright row 1RM. However, only 80% of the variation in 1.7 m box lifting performance could be accounted for by the best predictor equation. The results further support the concept that the predictability of anthropometric variables decreases as the complexity of the strength performance task increases.

The use of anthropometric data has also been used to predict selection in a variety of team sports. An example of this is a study by Keogh (1999b) which examined the use of anthropometric data to predict selection in an elite under 18 Australian rules football team. The results demonstrated that of the 40 Australian rules players, the selected players were taller ($P<0.05$), heavier, could jump higher and had greater upper body strength than non-selected players. The variables selected for discriminant analysis to selection were 3RM bench press, multistage fitness test shuttle run, counter movement jump (CMJ), height, mass and sit and reach. The discriminant analysis equation had an accuracy of 75.9%, 90.9% and 80% in predicting the selected, non-selected and all players, respectively. Interestingly, the equation had greater predictive ability to predict players who were not selected than those who were selected. The reason for this is unknown; however, the results suggest that a number of other factors (e.g. technical, tactical and psychological skills) may have also played a role in determining selection.

Somewhat comparable to Australian Rules football, rugby union and rugby league are collision field sports, characterised by intermittent play of maximal or near maximal exercise bouts with periods of low intensity rest. The rugby codes have forwards and backs who requiring different specific skills, and physiological and anthropometric demands (Appleby, Hori, & Dorman, 2009). Recently, the physiological and anthropometrical characteristics of rugby league players have been examined (Gabbett, 2007; King, Hume, Milburn, & Guttenbeil, 2009). In contrast to the previous study of Keogh (1999b), no significant differences were detected between selected and non-selected players for any of the physiological or anthropometric characteristics in 32-elite woman rugby league players (Gabbett, 2007). However, significant differences in body mass were found between forwards and backs. When data was analysed according to positional similarities, it was found that the hit-up forwards positional group were heavier, had greater skinfold thickness, and had lower 10-, 20-, and 40-m speed, muscular power, glycolytic capacity and estimated maximal aerobic power than the adjustable and outside backs positional groups (Gabbett, 2007). Similar results were reported in a review by King et al. (2009) who found that forwards had a higher body mass than backs in most published studies. King and colleagues (2009) found that amateur forwards had a higher estimated body fat %, lower body mass (90.8 kg), lower vertical jump height (38.1 cm) and lower estimated VO_2 max (38.1 $ml.kg.min^{-1}$) than semi-professional and professional players.

Recently the strength, power and anthropometric characteristics of professional rugby union players were examined (Appleby, et al., 2009). Subjects were placed into two groups (high playing ability group (high group) and low playing ability group (low group)) based on their performance of entire season. Large differences were found between forwards and backs in the two groups. For forwards, large effect sizes were found in skinfolds (ES = 0.86) and body mass (ES = 0.72) indicating that the low group had a higher body mass and body fat percentage. Moderate effect sizes were found in relative 1RM bench press (ES = 0.46) and relative 1RM squat (ES = 0.48) demonstrating that the high group forwards were relatively stronger than the low group. For backs, moderate effect sizes were found in skinfolds (ES = 0.45) and body mass (ES = 0.47) indicating that the low group had a higher body mass and body fat percentage. Interestingly the low group performed better in the bench press throws than the high group; however the high group was stronger in the 1RM squat (ES = 0.49). The results show that skinfolds and maximum strength appear to be the main factors that possibly differentiate the groups.

Interestingly, other studies have also indicated that both anthropometric and strength variables are able to differentiate professional players at different levels of competition. Hoffman, Vazquez, Pichardo and Tenenbaum (2009) found that lean body mass, speed, lower-body power, and grip strength were significantly correlated with baseball specific variables, and Keogh, Marnewick, Maulder, Nortje, Hume and Bradshaw (2009) found that lower handicapped golfers had significantly ($p < 0.05$) greater golf swing cable woodchop strength (28%) and greater (30%) bench press strength and longer (5%) upper arm and total arm (4%) length.

In the sport of strongman high levels of lower body strength and power would be advantageous in events such as the keg toss, log clean and press, farmers walk and truck pull. Currently no study has examined the relationship among lower body strength and power measures to strongman performance. Several studies have however investigated the relationship between isoinertial strength and power measures and vertical jump (VJ) performance. A summary of these studies is presented in Appendix 9. Many of the studies demonstrate a strong relationship between strength and power measures and VJ performance, suggesting to some extent that strength and power qualities influence performance in vertical jumping. Currently only three studies have examined the relationship between anthropometrics, strength variables and jump performance (Sheppard, et al., 2008; Ugarkovic, et al., 2002; Weiss, et al., 1997). Sheppard and colleagues (2008) reported strong correlations between height and CMVJ, and standing reach and CMVJ ($r = 0.77$ and 0.71; $p \leq 0.01$, respectively) in 21-elite volleyball players. Skinfold ratio was observed to be moderately correlated with absolute spike jump (SPJ) ($r = 0.52$; $p \leq 0.01$) suggesting to some extent that percentage of body fat may influence jump performance. Sheppard and colleagues (2008) analysed the seven best and seven worst jumpers for CMVJ and relative SPJ. Similar to the previous studies (Appleby, et al., 2009; Hoffman, Vazquez, Pichardo, & Tenenbaum, 2009; Keogh, 1999b; Keogh, et al., 2009b), significant and large differences existed between the groups for the traditional strength training lifts (1RM squat and power clean) and for the force-velocity variables assessed in the incremental load power profile. This analysis provides compelling evidence as the importance of these variables to jumping performance. Using regression analysis Sheppard et al. (2008) found that the single best predictors of CMVJ and relative SPJ was the depth jump from 0.35 m (DJ35) score which explained 84% and 72% of performance (respectively). This result is comparable to Ugarkovic et al. (2002) who found that standard strength, anthropometric, and body composition variables were moderate correlates ($r = 0.71$) of jumping performance in 33 elite junior male basketball players. Weiss and colleagues (1997) reported higher explanatory regressions ($r^2 = 0.80$ and 0.83) than Ugarkovic et al. (2002) using body composition and strength related variables, generated via velocity spectrum squats obtained from 52 men and 50 women. The results demonstrated that the more relative squatting power a person can generate at moderately fast velocities the greater the relative vertical jump (RVJ) distance. However, excessive body fat and the inability to produce force at higher velocities attenuate jump ability.

Speed is essential in many sports, and lower body muscle strength is considered an important component in sprinting performance. In the sport of strongman the farmers walk and truck pull involve a sprinting-type movement (under heavy loading) where the athlete's goal is to cover a distance in the fastest time possible. Sprint performance is a direct result of the impulse (the product of the mean force and time of contact) applied by the athlete against the ground during the propulsive phase of the stride (Dowson, Nevill, Lakomy, Neville, & Hazeldine, 1998). The rationale for incorporating strength training is based on the contention that increasing force output (strength) of the muscles involved in sprinting will improve acceleration and maximum velocity due to greater impulses being applied by the athlete (Cronin, Ogden, Lawton, & Brughelli, 2007). Several studies have focused on the relationship of isoinertial maximum strength tests and power tests to sprinting (A summary of these studies is presented in Appendix 9) with large variation among the studies ($r = -0.01$-0.94). Only one study (Kukolj, et al., 1999) has examined how maximal strength and anthropometric variables relate to sprinting performance. Twenty-four male university students were timed over 0.5-15m and 15-30m from the sprint start and measures of isometric strength (knee extensors, hip extensors and flexors) and power (height of CMJ and the mean power of leg extensors during continuous jumping) were collected, in addition to lean body mass and the % of both muscle and fat tissue (Kukolj, et al., 1999). The results obtained demonstrated that except for the CMJ all correlation coefficients were low and, therefore, non-significant. As a consequence multiple correlation coefficients were low ($r = 0.43$ and 0.56 for the acceleration and maximal speed phase, respectively). The results demonstrate that most of the anthropometric, strength and power tests could be poor predictors of sprinting performance and a better assessment of sprinting performance could be based on more specific tests that unfortunately require more complex measurements.

4.7 Conclusion

The kinanthropometric studies that have been conducted on the various aspects of movement performance have provided both strong and weak correlations suggesting to some extent that the specific relationship among these variables may vary as to the type and speed of the movement performed and among the development levels of athletes. Fat free mass, muscle CSA, and muscle circumference are the major determinants of the absolute weight an athlete is capable of lifting in the bench press, squat and deadlift. However, anthropometric measures are more indicative of lifting performance when the lift involves fewer muscle joints and muscle groups. Unlike traditional gym based exercises, strongman events involve complex lifting movements in multiple planes. Currently, no information exists in the scientific literature as to the relationship of gym based strength and anthropometric dimensions to strongman performance. Such an analysis could help aspiring strongman to gain some insight into their potential strengths and weakness for each common strongman event and what exercises they might need to concentrate on to overcome such limitations. Strength and conditioning coaches may also benefit as a number of strongman events appear quite specific to certain sporting movements (e.g. sprint-style sled/car/truck pull to scrimmaging and breaking tackles in American football or the rugby codes; tyre flip to cleaning out in rugby etc), an understanding of the kinanthropometric determinants of strongman performance may also apply to these more common sporting situations. Understanding the determinants of strongman event performance may also assist the strength and conditioning coach in selecting appropriate initial strongman training loads for their regular athletes and in predicting the possible potential that each athlete may display in these exercises. Research in this area will inform practice and give new insights into the effectiveness of traditional gym based training programmes to their strength transference to strength and power sports such as the sport of strongman.

References for this chapter are included in the list of references collated from the entire thesis at the end of the final chapter.

CHAPTER 5. INTERRELATIONSHIPS BETWEEN STRENGTH, ANTHROPOMETRICS AND STRONGMAN PERFORMANCE IN NOVICE STRONGMAN ATHLETES

5.1 Prelude

In recent years the sport of strongman has gained popularity with competitors performing functional movements in multiple planes under excessive loading. Realising that strongman performance will depend on some interaction between strength and anthropometric variables, examining these variables would help to develop our understanding as to their importance in various strongman events. Currently no peer-reviewed literature has examined strength and anthropometric variables in the sport of strongman. The first study presented in this thesis established how strongman competitors train, however, it did not establish how changes in strength and anthropometry as a result of resistance training affects strongman competition performance. Therefore, the purpose of this second study was to determine the interrelationships between strength, anthropometric variables and strongman competition performance. It was thought that analysis of these variables would allow for a more detailed understanding of strongman performance in a variety of events, thus providing information for subsequent investigations into the relationships between strength and anthropometrics to strongman competition performance.

5.2 Introduction

The sport of strongman is relatively new and little information exists in the scientific literature as to the determinants of successful strongman performance. It is well known that maximal strength is a major factor in determining performance across a variety of sports (Stone, et al., 2002), especially in sports such as weightlifting and powerlifting. However, what is not well known regarding strongman is what types of gym based strength are most related to performance and how this might be influenced by a variety of anthropometric characteristics. Understanding how strength and anthropometry relate to performance of a specific event or sport is a key issue in maximising the transfer of training to performance and therefore improving training efficiency (Pearson, et al., 2009).

Various strength and anthropometric variables have been tested in sports to evaluate the effects of training (Marey, et al., 1991), to select athletes (MacDougal, et al., 1991), to distinguish among different competition levels (Keogh, et al., 2009b) and to predict performance (Zampagni, et al., 2008). The rationale behind this approach is that the aforementioned variables are important for movement performance. However, the correlation studies that have investigated standard strength tests (for example, 1RM, maximum isometric voluntary force and rate of force development), anthropometrics, and movement performance have provided both strong (Keogh, et al., 2009b; Pearson, et al., 2009; Williams & Wilkinson, 2007; Zampagni, et al., 2008) and weak correlations (Kukolj, et al., 1999; Ugarkovic, et al., 2002) to performance. Thus, the specific relationship among these variables may vary from sport to sport and across different development levels of athletes i.e. elite to novice.

Of the studies so far that that have investigated the sport of strongman, the main emphasis has been on the metabolic and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of these exercises (Berning, et al., 2007; Keogh, et al., 2010b; Keogh, et al., 2010c; McGill, et al., 2009). Recently, the imprecise nature of the overload in strongman training when dealing with large groups of athletes has also gained attention (Baker, 2008). Baker (2008) attempted to develop a mixed training session of strongman exercises such as tyre flipping, log carrying and water filled conduit carrying coupled with some running conditioning for elite rugby league athletes. The training session was designed to elicit mean player heart rates of 165-175 beats per minute (bpm), in order to replicate the average heart rate (HR) conditions in a game. However due to the different bodyweights and strength levels of the athletes, two of the strongest players had a mean HR less than 165 bpm. This result suggests that higher levels of maximal strength and perhaps body mass may be advantageous in the sport of strongman. To date, however, no quantifiable evidence has been advanced to support this speculation.

Strongman events typically last from a few seconds to two minutes and incorporate functional movements in multiple planes that challenge the whole musculoskeletal system in terms of both strength and physiological demands (McGill, et al., 2009). Hence the sport of strongman is multi-factorial in nature with a range of muscular capabilities such as maximal muscular strength, power, anaerobic endurance, grip strength and core stability believed to be needed to perform successfully in the various strongman events (Havelka, 2004). To date no research has examined the relationships between maximal strength (as assessed in a gym based environment) and anthropometrics to strongman event and competition performance. Such research would be beneficial to strongman athletes and those wishing to participate in the sport of strongman to determine the degree to which structural dimensions and gym-based strength influence strongman performance. The purpose of this study was to develop our understanding as to what variables are the most important for success in novice strongman performance and help guide programming for individuals wishing to commence this sport.

Within the present study it was hypothesised that strong relationships would exist between gym based strength tests and standard anthropometric measures to strongman competition performance in novice strongmen. If such results are found, it would support traditional gym based training and the transferability of traditional training methods to strength and power sports such as strongman.

5.3 Methods

5.3.1 Experimental Approach to the problem

A cross sectional experimental study was designed by the authors to examine the relationship between maximal strength and anthropometrics to strongman competition performance in novice strongmen. Subjects competed in a strongman competition, and ten days later performed anthropometric and 1RM testing. The relationship between these variables was assessed by Pearson's product moment correlations. Our hypothesis was that, strong relationships would exist between gym based strength tests and standard anthropometric measures to strongman competition performance in novice strongmen, as higher levels of strength and body mass may be advantageous in the sport of strongman.

5.3.2 Subjects

Twenty-three male semi-professional rugby players volunteered to participate in this study. All subjects regularly performed 1RM testing as part of their fitness testing and had an extensive strength training background; including experience with the bench press, squat, deadlift, power clean and strongman exercises. The subjects were performing regular strength training as part of their pre-season training phase. The strongman competition organised for this study was either the first or second such competition that these athletes had competed. The subjects' mean (±SD) age, body mass, and heights were 22.0 ± 2.4 years, 102.6 ± 10.8 kg, and 184.6 ± 6.5 cm respectively. All subjects provided written informed consent after having being briefed on the potential risks associated with this research. This study was approved by the AUT University Ethics Committee, Auckland, New Zealand.

5.3.3 Strongman Assessment

Four strongman events were performed in a competition: the tyre flip; farmers walk; log clean and press; and truck pull. These events were chosen for this study as they: 1) are all common strongman events that assess varying types of strongman "strength"; 2) have all been considered appropriate conditioning exercises for a variety of athletes (Baker, 2008; Waller, 2003); and 3) were incorporated into the participants pre-season training so that the participants were familiar with these exercises. Strongman overall competition performance was calculated by adding each participants placing in each of the four events together. For example a participant who placed 1^{st}, 2^{nd}, 3^{rd} and 4^{th} across the four events gained a total score of 1 + 2 + 3 + 4 = 10 points. The participants with the lowest total and highest total score in the competition were first and last place, respectively.

After a ~10-minute standardised low intensity warm-up (i.e. aerobic training zone based on approximately 60 to 70% max HR) which consisted of dynamic stretching, and light jogging interspersed with bodyweight exercises, all subjects completed the four strongman exercises in a randomised order to prevent order effects, separated by a rest period of ~10-minutes. Specifics of each exercise are detailed below.

5.3.3.1 Tyre flip

The tyre (Doublecoin REM2 23.5R25 - mass of 280 kg, diameter of 163 cm and section width of 70 cm) was positioned on the ground in front of the participants. The participants were instructed to flip the tyre end-over-end as many times as they could in 40-seconds, using a technique similar to previously described (Keogh, et al., 2010c). A completed repetition was recognised when the tyre performed a full flip. The timing started on the referee's signal with the participant in their starting position with their hands on the tyre that was laid flat on the ground. The total number of tyre flips in 40-seconds was the outcome measure. A pictorial of the tyre flip is presented in Figure 15.

Figure 15: Tyre flip

Figure 16: Farmers walk

5.3.3.2 Farmers Walk

The customised farmers walk bars with a length of 1300 mm and handle thickness of 32 mm diameter, were each loaded with two 20 kg Eleiko training discs (Elieko Sport, Halmstad, Sweden) to give a total mass of 58 kg per bar. The farmers bars were positioned on the ground on each side of the participants who were instructed to pick up the bars in each hand and asked to complete as many 25 m laps as possible with a 180^{o}

degree turn at the end of each 25 m, over a 40-second period. The participants were allowed as many drops of the bars as they needed, although they were challenged to complete the greatest distance (measured to the nearest 0.5 m) that they could in 40-seconds, which was the outcome measure. Final measurement was taken at the front foot at the end of the 40-second period. The timing commenced with the first breaking of the farmers bars off the ground. A pictorial of the farmers walk is presented in Figure 16.

5.3.3.3 Log Clean and Press

The customised strongman metal log (diameter 20 cm) loaded with two 10 kg Eleiko Eleiko training discs (Elieko Sport, Halmstad, Sweden) to a total mass of 75 kg was positioned on the ground in front of the participants. Participants were instructed to bend their knees, lean forward and grasp the handles inside the metal log in a hammer (neutral) grip. The participants were instructed to lift the log from the ground to above their heads, as many times as possible in 60-seconds, which was the outcome measure. Participants could chose any technique they wished providing that, for a repetition to be counted, it had to start from the floor and required the participants to be standing upright with feet together, with knees extended, and elbows extended overhead. Once this position was obtained, the referee announced "good lift", and the participants could then lower the log for the next repetition. A pictorial of the log clean and press is presented in Figure 17.

Figure 17: Log clean and press

Figure 18: Truck pull

5.3.3.4 Truck Pull

The participants were strapped in front of a Toyota Hilux truck (mass of 2.5 tonnes) via a customised harness that crossed the waist and shoulders of the participant. The participants started the truck pull on a slight uphill grade of 1-2^{o} (performed on an asphalt surface) in a four-point power position and tried to accelerate the truck forward as quickly as possible using powerful triple extension of the lower body. The participants could use their arms to pull on the ground and to provide some stability if required. The distance that the truck was pulled (to the nearest 0.5 m) in 40-seconds was the outcome measure. A pictorial of the truck pull is presented in Figure 18.

5.3.4 Anthropometric Assessment

For the purposes of this study, anthropometry was sub-divided into three categories; height, body composition (body mass, fat free mass (FFM), muscle mass (MM), percentage of body fat (%BF)) and girth measurements. All anthropometric assessments i.e. height (stature) and segment girths, were assessed by one of the researchers who was a qualified (Level III) International Society for the Advancement of Kinanthropometry anthropometrist. The protocols used were those previously described by Norton & Olds (2004). Stature was measured using a portable stadiometer (Seca 214, Hangzhou, China). Segment girths (chest, upper arm (flexed), gluteal, thigh and calf) were measured using a Lufkin tape measure. Body composition was measured using a bioelectrical impedance machine (InBody230, Biospace, Seoul, Korea). Recent research indicates that the InBody230 is a valid measure of body composition as high correlations ($r > 0.85$) existed between the Inbody230 and Dual-energy X-ray absorptiometry (DEXA) for the range of body composition variables used in the present study (Yu, Rhee, Park, & Cha, 2010). All girths were measured in duplicate, with a technical error of measurement (TEM) of < 1% required. If the TEM > 1% for any variable, then a third measure was taken. The averages of the two (closest) measures were used for data analysis.

5.3.5 Maximal Strength Assessment

The maximal strength assessments were the squat, bench press, deadlift, and power clean one repetition maximum (1RM). The warm up, loading increments and rest periods used were according to previously established protocols (Wilson, 1994). Maximal strength testing was carried out over a two-day period. The bench press was performed on day one and the squat, power clean, and deadlift were performed on day two. Maximum strength was assessed by a 1RM performed with a free-weight Olympic-style barbell. Bench press and squat 1RM were assessed using the methods outlined by Baker (1999b). Completed lifts in the deadlift and power clean were recognised when the participants were standing fully upright with the applied load.

For the purpose of this study, each participants squat 1RM and body mass were added to create the variable ‘system force’. This variable was created as the results of Baker (2008) and Keogh et al. (2010b) suggest that ‘system force’ could be highly related to strongman performance, especially in the truck pull.

5.3.6 Statistical Analysis

Means and standard deviations were used as measures of centrality and spread of data. The relationship between 1RM, and anthropometrics, to strongman competition performance were analysed using Pearson correlation coefficients, which based on the sample size of 23 had uncertainty (90% confidence limits) of ~ ±0.37 (Hopkins, 2007). The magnitudes of correlations were described as trivial (0.0-0.1), low (0.1-0.3), moderate (0.3-0.5), large (0.5-0.7), very large (0.7-0.9), or nearly perfect (0.9-1.0) (Hopkins, 2006).

Inferences about the true (large-sample) value of the correlations were based on uncertainty in their magnitude (Batterham & Hopkins, 2006); if the 90% confidence interval (derived for correlations via the Fisher z transformation) (Fisher, 1921) overlapped small positive and negative values (i.e. ±0.1), the magnitude was deemed unclear; otherwise the magnitude was deemed to be the observed magnitude. For trivial correlations the upper confidence limits were ~±0.37. Thus the power of this study was such that only correlations >0.28 and <-0.28 were considered clear. Correlations were analysed using the Statistical Package for the Social Sciences (Version 16.0, SPSS for Windows), and 90% confidence intervals were calculated using a statistical spreadsheet designed by Hopkins (2007).

5.4 Results

The physical and performance characteristics of the subjects are reported in Table 10.

Table 10: Descriptive statistics (mean ± standard deviation), for strongman events, strength, and anthropometric measures.

Parameters	Mean	±	SD
Age (years ± months)	22.0	±	5.6
Height (cm)	184.5	±	6.5
Strongman Performance Measures			
Tyre flip (reps)	6.6	±	2.3
Log clean and press (reps)	7.6	±	3.2
Truck pull (m)	18.8	±	8.5
Farmers walk (m)	64.0	±	9.9
Strength measures			
Bench Press (kg)	132.2	±	16.6
Squat (kg)	167.1	±	22.8
Deadlift (kg)	189.4	±	17.7
Power clean (kg)	105.6	±	10.3
System Force measure			
Body mass + 1RM squat (kg)	269.6	±	29.4
Bioelectrical impedance Measures			
Body mass (kg)	102.2	±	10.8
FFM (kg)	88.1	±	8.6
MM (kg)	51.4	±	5.2
Body Fat (%)	13.6	±	4.7
Girth Measures			
Max flexed arm girth (cm)	41.1	±	2.7
Chest girth (cm)	111.4	±	4.9
Gluteal girth (cm)	107.8	±	4.7
Mid thigh girth (cm)	61.8	±	2.8
Calf girth (cm)	42.0	±	2.7

Key: FFM = Fat Free Mass, MM = Muscle Mass.

The results for the interrelationships among strength and anthropometric variables detailed in Table 11 showed a spread of trivial to very large correlations. Clear large to nearly perfect correlations existed between the system force measure (body mass + 1RM squat) and all 1RM strength measures (r = 0.57-0.96). The interrelationships between body composition (body mass, FFM and MM) and strength measures typically showed clear moderate to large correlations for all variables (r = 0.47-0.59) except the deadlift (r = 0.24-0.29).

Low and trivial correlations were observed for height and strength measures (r = -0.09-0.12), and height and girth measures (r = 0.10-0.27) except for gluteal girth where a clear moderate correlation existed (r = 0.43). The interrelationships of height to body mass, FFM and MM show clear moderate to large correlations (r = 0.49-0.73).

The interrelationship among girth and strength measures show trivial to very large clear correlations (r = 0.02-0.82). Clear moderate to very large correlations existed between flexed arm girth, chest girth, mid thigh girth, calf girth and the bench press and squat (r = 0.45-0.82).

Table 11: Intercorrelation matrix for maximal strength and anthropometrics variables.

	Bench Press	Squat	Deadlift	Power - clean	System Force	Body mass	FFM	MM	Body fat (%)	Height	Flexed arm girth	Chest girth	Gluteal girth	Mid thigh girth	Calf girth
Bench Press (kg)	1.00														
Squat (kg)	0.69*	1.00													
Deadlift (kg)	0.42†	0.56*	1.00												
Power clean (kg)	0.47†	0.62*	0.37†	1.00											
System Force (kg)	0.70**	0.96**	0.57*	0.65*	1.00										
Body mass (kg)	0.47†	0.54*	0.24	0.26	0.74**	1.00									
FFM (kg)	0.57*	0.53*	0.28	0.48†	0.69*	0.85**	1.00								
MM (kg)	0.59*	0.55*	0.29^	0.50*	0.71**	0.84**	1.00*	1.00							
Body fat (%)	-0.08	0.02	-0.01	-0.32†	0.03	0.39†	-0.15	-0.17	1.00						
Height (cm)	0.12	-0.09	-0.09	0.10	0.04	0.49†	0.73**	0.72**	-0.37†	1.00					
Flexed arm girth (cm)	0.82**	0.72*	0.49†	0.39†	0.80**	0.70**	0.65*	0.65*	0.27	0.10	1.00				
Chest girth (cm)	0.45†	0.50*	0.14	0.06	0.64*	0.83**	0.57*	0.57*	0.63*	0.15	0.60*	1.00			
Gluteal girth (cm)	0.22	0.20	0.17	0.02	0.41†	0.88**	0.70**	0.69*	0.51*	0.43†	0.39†	0.74**	1.00		
Mid thigh girth (cm)	0.51*	0.53*	0.12	0.22	0.41†	0.89**	0.70**	0.70**	0.51*	0.27	0.76**	0.89**	0.69*	1.00	
Calf girth (cm)	0.67*	0.52*	0.25	0.39†	0.64*	0.78**	0.64*	0.65*	0.42†	0.12	0.79**	0.74**	0.57*	0.77**	1.00

** Clear, very large correlation. *Clear, large correlation. † Clear, moderate correlation. ^ Clear, low correlation.
Key: FFM = Fat Free Mass, MM = Muscle Mass, System Force = Body mass + 1RM Squat

The results for the interrelationships among strongman performance and strength measures, body composition, height and girth measures detailed in Table 12 show a range of trivial to very large clear correlations (r = 0.03-0.87). Clear moderate to very large correlations existed between overall strongman competition performance and 1RM strength measures (r = 0.45-0.85). Clear moderate to very large correlations existed among 1RM strength measures and strongman event performance (r = 0.44-0.82), except for the deadlift where unclear and clear low correlations existed with truck pull (r = 0.17) and tyre flip performance (r = 0.29) respectively. The system force measure (body mass + 1RM squat) demonstrated clear large to very large correlations with all strongman event performance (r = 0.64-0.87) and was the highest reported correlation (r = 0.87) with overall strongman competition performance in this study.

The interrelationship between body composition variables (body mass, FFM, MM and body fat %), and all aspects of strongman performance show trivial to large clear correlations (r = 0.05-0.73). Clear moderate to large correlations existed for body mass, FFM and MM to all aspects of strongman performance (r = 0.43-0.73). Unclear trivial correlations existed between body fat percentage and all aspects of strongman performance (r = 0.05-0.13) except for the truck pull where a clear moderate correlation was observed (r = 0.38).

Unclear low and trivial interrelationships existed for height and all aspects of strongman performance (r = -0.15-0.03). The relationships among the girth measures and all aspects of strongman performance typically showed clear moderate to very large correlations (r = 0.33-0.79). Exceptions were for gluteal girth and log clean and press (r = 0.27), chest girth and farmers walk (r = 0.28) and calf girth and farmers walk performance (r = 0.19) which all showed unclear low correlations.

Table 12: Intercorrelation matrix between strength, anthropometrics and strongman events and overall competition performance.

Parameters	Log clean & Press (reps)	Truck pull (m)	Farmers Walk (m)	Tyre Flip (reps)	Strongman competition performance
Height (cm)	-0.15, ±0.36	0.12, ±0.36	0.14, ±0.36	0.03, ±0.37	0.05, ±0.37
Strength performance measures					
Bench Press (kg)	0.76, ±0.16**	0.56, ±0.25*	0.46, ±0.29†	0.70, ±0.19**	0.78, ±0.15**
Squat (kg)	0.71, ±0.21**	0.61, ±0.26*	0.64, ±0.25*	0.82, ±0.15**	0.85, ±0.12**
Deadlift (kg)	0.48, ±0.31†	0.17, ±0.37	0.55, ±0.28*	0.29, ±0.35^	0.45, ±0.31†
Power clean (kg)	0.67, ±0.23*	0.44, ±0.32†	0.45, ±0.31†	0.48, ±0.31†	0.60, ±0.26*
System Force measure					
Body mass + 1RM squat	0.71, ±0.22**	0.68, ±0.47*	0.64, ±0.26*	0.81, ±0.15**	0.87, ±0.11**
Body Composition					
Body mass (kg)	0.45, ±0.30†	0.73, ±0.19**	0.47, ±0.30†	0.51, ±0.29*	0.66, ±0.23*
FFM (kg)	0.43, ±0.31†	0.57, ±0.27*	0.48, ±0.30†	0.53, ±0.28*	0.63, ±0.24*
MM (kg)	0.44, ±0.31†	0.57, ±0.27*	0.49, ±0.29†	0.55, ±0.27*	0.64, ±0.24*
Body fat (%)	0.13, ±0.36	0.38, ±0.32†	0.06, ±0.37	0.05, ±0.37	-0.18, ±0.36

Girth Measures					
Flexed arm girth (cm)	0.68, ±0.22*	0.74, ±0.19**	0.46, ±0.31†	0.66, ±0.23*	0.79, ±0.16**
Chest girth (cm)	0.54, ±0.28*	0.66, ±0.23*	0.28, ±0.34	0.49, ±0.30†	0.57, ±0.27*
Gluteal girth (cm)	0.27, ±0.36	0.54, ±0.28*	0.42, ±0.32†	0.33, ±0.34†	0.48, ±0.31†
Mid thigh girth (cm)	0.50, ±0.30*	0.70, ±0.21**	0.35, ±0.34†	0.52, ±0.29*	0.64, ±0.24*
Calf girth (cm)	0.75, ±0.18**	0.68, ±0.22*	0.19, ±0.34	0.67, ±0.23*	0.70, ±0.21**

Data expressed as: r, ±90% CI

** Clear, very large correlation. *Clear, large correlation. † Clear, moderate correlation. ^ Clear, low correlation.
FFM = Fat Free Mass, MM = Muscle Mass

The interrelationship between strongman competition performance and strongman event performance detailed in Table 13 show clear large to very large correlations (r = 0.69-0.88). Clear moderate to very large correlations were observed between individual strongman events (r = 0.31-0.81). The tyre flip and farmers walk had the strongest and weakest interrelationships (respectively) with overall strongman competition performance.

Table 13: Intercorrelation matrix between strongman events and overall competition performance.

	Tyre flip (reps)	Log clean and press (reps)	Truck pull (m)	Farmers walk (m)	Strongman competition performance
Tyre flip (reps)	1.00				
Log clean and press (reps)	0.81**	1.00			
Truck pull (m)	0.64*	0.59*	1.00		
Farmers walk (m)	0.45†	0.31†	0.47†	1.00	
Strongman competition performance	0.88**	0.82**	0.82**	0.69**	1.00

** Clear, very large correlation. *Clear, large correlation. † Clear, moderate correlation

5.5 Discussion

The aim of the present study was to examine the interrelationships between 1RM strength measures and anthropometric variables to strongman competition performance in novice strongman competitors. It was hypothesised that strong relationships would exist among many of these variables.

The results of this study provide the first data on the interrelationships between 1RM strength measures and anthropometric variables to strongman competition performance. As hypothesised, strong relationships were observed between many 1RM strength and anthropometric measures to strongman competition performance, with the highest correlate of overall strongman competition performance being system force (body mass + 1RM squat) ($r = 0.87$). This result suggests that being heavy and strong in the squat is advantageous for successful strongman performance.

The results of the present study demonstrated that the tyre flip and the farmers walk had the strongest and weakest interrelationships with overall strongman competition performance ($r = 0.88$ and 0.69), respectively. The farmers walk may have assessed different strength qualities (e.g. foot speed and grip strength) instead of maximal strength compared to the other strongman events (Havelka, 2004). This was reflected in the clear large correlation between the deadlift and farmers walk ($r=0.55$) where it's generally thought that grip strength can be a primary determinant of deadlift performance.

The strongest correlation that existed between the farmers walk and the other strongman events was the truck pull, where a clear moderate correlation was shown ($r = 0.47$). This may be due to some similarities in the movements associated with these exercises. The farmers walk and truck pull both involve horizontal motion of the total body with the feet in a split position, compared to the log clean and press and tyre flip which are predominantly performed with two feet side by side in a vertical plane. Differences also exist between these events in the types of strength required. The log clean and press and tyre flip involve upper body pushing strength which is not seen in the farmers walk and truck pull events.

Of the 1RM strength measures the squat and bench press demonstrated the highest interrelationships with overall strongman competition performance (r = 0.85 and 0.78), respectively. The results demonstrate that the squat had the strongest relationship to all the strongman events except the log clean and press (r = 0.71), where the bench press showed a slightly stronger relationship (r = 0.76). This finding may due to the specificity of the pressing action in the log press and the transferability of the bench press strength in performing this action. Previous research has shown significant relationships between bench press strength and grinding performance in Americas Cup sailors (Pearson, et al., 2009). Significant relationships have also been reported between squat strength and sprinting ability (McBride, et al., 2009). Schoenfeld (2010) suggested that the squat has biomechanical and neuromuscular similarities to a wide range of functional movements. The results from the current study support the use of the bench press and squat as fundamental gym based exercises for novice strongman competitors.

The clear large correlation between the power clean and the log clean and press (r = 0.67) could be explained by the similarities associated with these exercises (i.e. main agonists, specific joint angles and direction of force application, muscle sequence patterns, specific postures, and velocities of movement). Stone and colleagues (2007) have suggested that the more similar a training exercise is to actual physical performance, the greater the probabilities of transfer.

Low to clear large correlations existed between the deadlift and all aspects of strongman performance (r = 0.17-0.55). The deadlift demonstrated low interrelationships to the truck pull and tyre flip (r = 0.17 and 0.29 respectively). The low relationship associated with the truck pull and deadlift may be due to the lack of biomechanical specificity associated with these exercises. The clear low correlation between the deadlift and tyre flip is however more surprising, as the start of the tyre flip appears similar to the posture employed at the beginning of a deadlift. Subjects were however, tested with the conventional deadlift and the tyre flip starts in a semi-sumo deadlift position. Biomechanical differences exist between sumo and conventional deadlifts, with significant differences in ankle and knee moments and moment arms (Escamilla, et al., 2000a). The sumo deadlift has higher quadriceps involvement compared to the conventional deadlift (Escamilla, et al., 2000a), which may help explain the very large clear correlation between the squat and tyre flip (r = 0.82).

Recent research has also demonstrated that the duration of the second pull (i.e. the phase where the tyre moved from just above the knee to the hands-off position prior to the push) and not the first pull (i.e. the phase where the tyre first comes of the ground to it vertically rising to just above knee height) was the primary difference between slow and fast flips, further diminishing the expected relationship between deadlift strength and tyre flip performance (Keogh, et al., 2010c). Interestingly, the present study also found unclear low correlations between the deadlift and the anthropometric variables (height, FFM, body mass, chest girth and mid-thigh girth) which are in contrast to the moderate correlations previously reported (Keogh, et al., 2005; Mayhew, et al., 1993b, 1993c).

Clear moderate and large correlations were demonstrated between body mass and all aspects of strongman performance. The range of correlations between body mass and strongman performance in this study ($r = 0.45-0.73$) are comparable to the correlations between body mass and 1RM strength performance previously reported (Hart, et al., 1991; Keogh, et al., 2005; Mayhew, et al., 1991; Mayhew, et al., 1993a; Mayhew, et al., 1993b, 1993c). These results suggest that in trained athletes a larger body mass is beneficial for strength performance, reflecting greater FFM and larger muscle cross sectional area. Previous research has established that the force a muscle can exert is related to its cross sectional area (Komi, 1979), which is more beneficial for muscle force production (Brechue & Abe, 2002; Keogh, et al., 2009a).

The correlations between FFM and all aspects of strongman performance were clear and moderate, however the log clean and press had the weakest relationship of the four strongman exercises to FFM ($r = 0.43$). This result may be due to the complexity of the log clean and press movement. This type of movement which is similar to the clean and jerk in Olympic lifting incorporates a vast array of musculature and a wide range of abilities. Athletes would appear to not only need strength, but also balance, coordination, flexibility and speed when performing this movement. Prior research has shown that the relationships between anthropometric variables and strength performance decrease with exercise complexity (Keogh, et al., 2005; Mayhew, et al., 1993b). Another contributing factor that may explain the weaker relationship between FFM and the log clean and press in this study was that the log clean and press went for 60-seconds rather than the 40-seconds used for the other strongman events. Hence, the 60-second log clean and press event may have measured somewhat different strength qualities i.e. muscular and anaerobic endurance than the other strongman exercises. While we acknowledge this limitation, the log clean and press is commonly performed for 60 – 90-seconds in competition. In addition, it was important when running correlations that all subjects were able to obtain a non-zero score for each of the four events. We felt that if the log clean and press was limited to 40-seconds, a heavier weight would have been needed to get a spread of performance between these athletes. The smaller, weaker athletes might then have got no repetitions, which would then have reduced the sample size and increased the uncertainty confidence limits for all correlations involving the log clean and press.

As with all strongman competitions, all competitors in the present study performed the strongman events with the same loads. While we acknowledge that the larger and stronger individuals were at an advantage, the purpose of the present study was to test the hypothesis that strong relationships would exist among the dependent and independent variables represented in this study. In addition, our competition followed standard strongman competition rules as the score in each event was determined by placement. However, in our scoring system the subjects' with the lowest total and highest total score in the competition were first and last place, respectively. This is in contrast to the scoring method seen in the World's Strongest Man (WSM) where the highest score is the winner and lowest score is last place. However, both scoring systems would have determined a similar outcome.

The correlations between FFM and strongman event and overall performance ($r = 0.43$-0.63) in the present study are comparable to correlations reported between FFM and 1RM strength performance in college football players (Mayhew, et al., 1993b, 1993c) and predominantly national-level powerlifters (Keogh, et al., 2005). However, the correlations from the present study are much lower than that reported ($r = 0.86$-0.94) in elite powerlifters (Brechue & Abe, 2002). Deliberate practice, technique and neurological adaptations (i.e. motor unit firing rate and motor unit synchronisation) may explain the higher correlations reported for elite than sub-elite powerlifters. It would be interesting if the greater correlations found between FFM and performance for elite than sub-elite powerlifters would also apply to elite compared to novice strongman competitors.

The clear moderate and very large correlations that existed between height, and FFM, and MM, and body mass (r = 0.73, 0.72 and 0.49 respectively), supports the concept that taller individuals are heavier and have greater FFM and therefore greater potential to lift heavier loads. However, powerlifters and Olympic weightlifters whose sports involve the lifting of very heavy loads are generally average to below average in height and have relatively short limbs (Keogh, et al., 2007; Marchocka & Smuk, 1984; Mayhew, et al., 1993a; Ward, Groppel, & Stone, 1979). These anthropometric characteristics would be advantageous in these weight-lifting sports as the work and torque required to lift a load are proportional to the length of the lever (body segment) (Keogh, et al., 2007, 2008). Taller individuals with longer levers require more muscular work and torque to lift a given load which may be disadvantageous for strength exercises such as the squat and pressing events. In the sport of strongman being taller may be advantageous in some events such as the atlas stones (when loading on to high platforms), vertical keg toss and carrying events such as the farmers walk due to the relationship between height, step length and running speed. Interestingly, in the present study very low and trivial relationships existed between height and all measures of 1RM and strongman performance. Such a result suggests that height and limb segments may not be determining factors in novice strongman competitions, at least those involving the tyre flip, farmer's walk, log clean and press, and the truck pull. This result does raise some interesting questions for these events with many strongman competitors believing that longer arms and a longer torso allow for greater leverage for the tyre flip. While trunk and arm length are correlated to overall stature (within certain limits) (Carter, Aubry, & Sleet, 1982), the present study did not measure trunk or limb lengths. Future studies may therefore wish to examine the role of limb and trunk proportions in strongman events like the tyre flip.

The results of the present study demonstrate that body fat percentage was only trivially related to all aspects of strongman performance except the truck pull where a clear moderate correlation was observed (r = 0.38). This relationship suggests that higher levels of body fat may be somewhat beneficial in the truck pull where higher levels of body mass could assist in developing greater momentum to overcome the inertia of the truck at the start of the pull.

Of the girth measures, flexed arm girth and calf girth demonstrated the highest interrelationships with strongman competition performance (r = 0.79 and 0.70), respectively**.** This was also the case for the relationship between girths and 1RM strength, whereby the flexed arm girth and calf girth had the greatest relationship to all strength scores except for squat, whereby the calf girth correlation (r = 0.52) was slightly less than mid-thigh girth (r = 0.53).

The relationship between flexed arm girth and squat (r = 0.72) was very similar to what had been previously reported for powerlifters (Keogh, et al., 2005), however the relationship between max flexed arm girth and the bench press was slightly higher in the present study (r = 0.82) compared to Keogh and colleagues (R = 0.71) (2005). Individuals with larger arms performed better in the bench press exercise, and in overall strongman competition performance. However, the current study indicated that resistance trained athletes with greater thigh size did not always have greater lifting ability in the squat. This finding was similar to that found by Mayhew and colleagues (1993b). Interestingly, individuals with larger thigh size performed better in the truck pull. The differences between these strength exercises and the magnitude of the relationship with thigh girth may be due to the different muscle contribution and postures employed in the squat and truck pull. The posture employed in the truck pull may place more emphasis on the quadriceps whereas in a wider stance back squat a larger relative contribution might come from the hamstrings, gluteus group and erector spinal muscles. The higher association between thigh girth and truck pull rather than squat performance may also reflect the very strong positive relationship between thigh girth and body mass (r = 0.89), whereby greater body masses assist in the truck pull as long as the athlete is leaning forwards throughout the pull.

An unclear low correlation between calf girth and farmers walk (r = 0.19) was observed in the present study. This is surprising as it is known that the plantarflexors contributes to the gait cycle (mid-stance and terminal stance) through control of ankle dorsiflexion and plantarflexion (Hamill & Knutzen, 2009). A greater calf girth would be thought to allow for more force to be produced during plantarflexion which would be beneficial in the gait cycle under heavy loading. The results of the present study may indicate that muscle contribution and gait kinematics during the normal gait cycle may change considerably in an event such as the farmers walk. However, further research is needed to validate such a view.

There were a number of limitations within the present study. We assessed strongman performance in only four events with semi-professional rugby union players. Further research is therefore required to confirm if similar results would be found in competitions involving more or other types of strongman events and for a different sample group, such as elite strongman competitors. It was also observed that loading limitations may have existed in the farmers walk. However, the handles (which had been used in training by all subjects) were larger in diameter than regulation barbell size and were quite smooth, thereby increasing the grip demands over what would be expected in many other farmers bars. It should also be noted that correlations can only give insights into associations and not into cause and effect; therefore longitudinal studies are needed to provide valid information in regard to how changes in body composition and/or maximal strength affect strongman performance.

In conclusion, this study investigated relationships between anthropometric variables and 1RM strength measures to strongman competition performance in novice strongman athletes. The highest interrelationship with strongman competition performance was system force (body mass + 1RM squat). The results of this study indicate that maximum strength and anthropometric variables and play a significant role in the determination of strongman performance in novice strongman athletes.

5.6 Practical Applications

Understanding the relationships that exist between maximal strength, anthropometrics and strongman performance can assist in the identification of the determinants of strongman performance, hence providing a theoretical underpinning for training practice in this sport. The data represented in this study demonstrates the strength and anthropometric requirements to compete successfully in a novice strongman competition. The data supports traditional based training and the transferability of traditional training methods to the sport of strongman. This data can be used by strength and conditioning coaches and novice strongman competitors to help guide programming, which can be used to maximise the transfer of training to strongman performance and therefore improve training efficiency.

References for this chapter are included in the list of references collated from the entire thesis at the end of the final chapter.

CHAPTER 6. GENERAL SUMMARY

6.1 Summary

In the past decade, the sport of strongman has recorded a surge in popularity in many countries, both as a spectator sport and in terms of the number of active competitors. Strongman events have been deemed more functional than many traditional gym based training methods by a number of individuals. Events such as the farmers walk, sled pull and truck pull represent functional movements in multiple planes that challenge the body's linkage in a different way than traditional gym based resistance training approaches. Many strength and conditioning coaches have therefore started using a number of strongman exercises to improve the performance of their athletes, as these functional exercises are deemed more 'sports specific'.

A review of the literature revealed that little information exists on the sport of strongman. Of the studies that have investigated the sport of strongman, the main emphasis has been on the metabolic and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of these exercises. This master's thesis sought to provide original academic research on the sport of strongman. Two studies were designed to provide those involved with strongman and strength and conditioning with a more detailed understanding of how these athletes train, and what strength and anthropometric characteristics contribute to successful strongman performance.

The first study included in this thesis was a cross sectional exploratory descriptive study. Elite strongman competitors have been observed in competitions to pull trucks weighing in excess of 20-tonnes. Despite this, no study has investigated how these athletes train to cope with the physiological stresses associated within this sport. Thus, chapter 3 aimed to describe the strength and conditioning practices employed by strongman competitors and determine how well strongman competitors apply the scientific principles of resistance training. The 65-item survey revealed that all of these athletes performed traditional gym based resistance exercises as part of their strongman training. The majority of these athletes performed hypertrophy, strength and power training and incorporated some form of periodisation in their training. The majority of competitors' utilised training methods designed to increase explosive strength and power. These included the use of bands, compensatory acceleration methods, lower body plyometrics, and Olympic lifts and their derivatives. The findings demonstrate strong similarities of strength and power training methods between strongman competitors, weightlifters and elite powerlifters.

The survey demonstrated that the majority of strongman athletes also incorporated aerobic and anaerobic conditioning into their strongman training, with sport specific aerobic/anaerobic conditioning being the most commonly reported training practice. Interestingly, the survey revealed differences in a strongman events training day. Half of the athletes used strongman implements training only sessions while the other half incorporated strongman implements with gym work in the same training session. This demonstrates that strongman event training can vary among competitors and varieties of resistance equipment can be utilised and incorporated into a strongman training session. Of all the strongman events, the farmers walk, log press and stones had the highest percentage of use among the strongman competitors surveyed in this study. It is not yet understood why these events are most favoured. It may be the accessibility of these training implements and the different types of stress that these events place on the body's system are similar to other less widely performed strongman events.

The open ended question at the end of the survey also provided valuable insight into these athletes training practices. It revealed that strongman competitors vary their training and periodically alter training variables (i.e. sets, reps, loads) during different stages of their training. The type of events (i.e. max effort or reps event) in a competition can determine training loading strategies, with competitors determining the most efficacious training protocols for each event.

The survey demonstrated that strongman competitors incorporate a variety of strength and conditioning practices that are focused on increasing muscular size, and the development of maximal strength and power. The majority of strongman competitors use training variables (i.e. loads, sets, reps and rest periods) that are within the suggested guidelines for the various phases and types of training. The results of this study support the hypothesis that strongmen competitors follow many scientifically based strength and conditioning practices.

Understanding how strength and anthropometrics apply to the sport of strongman would be a key issue to maximise the transfer of training to strongman performance. Despite this, no study to date has investigated these relationships in the sport of strongman. Thus, the purpose of the cross sectional experimental study in chapter 5 was to investigate the inter-relationships between strength, anthropometrics, and strongman performance in novice strongman athletes. Twenty-three semi-professional rugby union players with resistance training and some strongman training experience were assessed for anthropometry (height, body composition, and girth measurements), maximal isoinertial performance (bench press, squat, deadlift and power clean), and strongman performance (tyre flip, log clean and press, truck pull and farmers walk). The magnitudes of the relationships were interpreted using Pearson correlation coefficients. Strong relationships were observed between many anthropometric variables, 1RM strength measures and strongman competition performance.

The highest correlate with overall strongman competition performance was system force (body mass + 1RM squat) ($r = 0.87$). This result suggests that having high body mass and being strong in the squat is advantageous for successful strongman performance. Of the 1RM strength measures the squat and bench press demonstrated the highest interrelationships with overall strongman competition performance. Interestingly, the squat demonstrated clear moderate to very large relationships between all aspects of strongman event and overall competition performance, indicating the importance of maximal squat strength to successful strongman performance. Clear moderate and large correlations were also demonstrated between body mass and all aspects of strongman performance, suggesting that a larger body mass is beneficial for strength performance. Interestingly, low and trivial relationships existed between height and all measures of strongman performance. This result suggests that height and limb segments may not be determining factors in novice strongman competitions, at least those involving the tyre flip, farmers walk, log clean and press, and the truck pull.

Of the girth measures, flexed arm girth and calf girth demonstrated the highest interrelationships with strongman competition performance and 1RM performance. The results indicate that individuals with larger arms and calves may reflect a larger body mass and a greater potential to produce force which is beneficial for strength performance. The results of this study have established that body structure and common gym based exercise strength are meaningfully related to strongman performance in novice strongman athletes.

6.2 Practical Applications

The strongman studies reviewed in the literature give a good indication of what is required in the sport of strongman. The studies show that the athletes need power through mid-range, metabolic conditioning and high core and hip abduction strength/stability, grip and overall body strength. The data represented in this thesis indicates how athletes could train for the sport of strongman and what strength and anthropometrics variables may be most important.

Based on the findings of this thesis, the evidence indicates that athletes wishing to compete in the sport of strongman should have a periodised plan that includes;

1) Training to increase muscle size, with a large emphasis on increasing upper arm and calf girth. Upper arm girth may provide the best anthropometric assessment for potential strongman performance.

2) Training to increase whole body mass, most particularly fat free mass.

3) Training to increase maximal strength, with a large emphasis on increasing maximal squat and bench press strength. 1RM squat and bench press may provide the best 1RM strength assessments for potential strongman performance.

4) Training to increase explosive power (i.e. rate of force development). Athletes can use a wide variety of training loads providing the intention is to move the load as fast as possible. A wide variety of power training methods can be used including; bands and chains, lower body plyometrics, and Olympic lifts and their derivatives.

5) Sport specific aerobic/anaerobic conditioning. Examples of this would be using lighter weights for the farmers walk in order to cover larger distances, or lighter weights in the log clean and press for more repetitions.

6) Strongman implements training at least once a week. This could include exercises such as the farmers walk, log clean and press and stones that challenge the body's linkage and neuromuscular system in different ways.

7) Variation in training variables (i.e. sets, reps, loads). Variation is needed for a planned progression and to prevent training plateaus, over-reaching and possible injuries.

8) Determining the most efficacious training protocols for each strongman event (i.e. max effort or reps event). Competitors could change the type, duration and intensity of their training programmes according to the upcoming competition events.

Strongman competitors, athletes, and strength and conditioning coaches can use this data as a review of strength and conditioning practices and as a possible source of new ideas to diversify and improve their training practices. The data represented in this thesis can be used by strength and conditioners and strongman competitors to help guide programming, which can be used to help maximise the transfer of training to strongman performance and therefore improve training efficiency.

6.3 Limitations

The authors note and acknowledge the following limitations and delimitations of the research performed.

6.3.1 Exploratory Study

1) Coverage and self-selection bias in the training practices study may be correlated with traits that affect training practice.

2) The training practices study was in English so non-English speaking competitors may not have been able to participate.

3) No cross-case comparison was made between the training practices of elite versus non-elite strongman competitors.

4) More open ended questions in the training practices study would have provided more opportunity for subjective responses, which could have provided greater insight and information on the training practices of these athletes.

6.3.2 Correlation Study

5) The correlation study assessed strongman performance in only four events.

6) Loading limitations and increased grip demands may have existed in the farmers walk. The load of 60 kg was used which is lighter than what would normally be used for this event. This was required as the farmers bars handles were larger in diameter than regulation barbell size and were quite smooth, thereby increasing the grip demands over what would be expected in many other farmers bars.

7) Due to the limited number of strongman competitors in this country we used semi-professional rugby union players with some strongman training experience in the correlation study. Thus, the findings of the correlation study may only be applied to novice competitors. We would have liked to use 'true' strongman competitors, however it would not have been practical to travel to a strongman competition as we would not have been able to gather all the data from the tests we conducted in our study (i.e. maximal strength tests). Furthermore, we would have not been able to randomise the strongman event order to reduce the order effect.

6.4 Directions for Future Research

This thesis has made a substantial original contribution to our knowledge and understanding of the sport of strongman. The strength and conditioning practices of strongman competitors and the interrelationships between maximal strength (assessed in a gym based environment), anthropometrics and strongman performance have now been examined. However, due to the lack of research done on the sport of strongman, a number of areas still urgently require investigation.

1) Firstly, the possible injury potential associated with this form of training. It is likely that strongman training would also have somewhat unique injury risks and epidemiology due to the high spinal and hip loading shown to be associated with this type of training. A survey investigating the injury epidemiology of strongman would

offer comprehensive information about the possible risks associated with strongman type training. This knowledge could help guide programming into how and what type of strongman type exercises athletes and strength and conditioning coaches could incorporate into their programmes, particularly in relation to the progression of exercise prescription.

2) Research is needed to examine the kinetics associated with strongman exercises (such as the heavy sled pull, farmers walk and truck pull) and validate the use of these strongman type exercises to improve performance capabilities. Such data could help guide programming and give support to the use of strongman type exercises in strength and conditioning programmes.

3) Research should also investigate the physiological stress strongman training places on the body's systems. Studies could investigate the metabolic and endocrine responses to a strongman training session. Such data could give strength and conditioning coaches and sport scientists some understanding of the acute stresses that strongman training imposes on the system and some indication into the potential acute and chronic metabolic and morphological adaptations to such training.

4) The use of strongman type exercises such as the heavy sled pull as a form of complex training is worthy of investigation. A strongman event like the heavy sled pull may help increase sprint performance. The heavy sled pull may be more physically demanding and induce greater muscle fibre recruitment of the sprint-specific motor units than a traditional exercise like the squat. As such, the use of the heavy sled pull may elicit greater neural and muscular mechanisms that could lead to even greater acute increases in explosive sprinting capability.

5) The training practice study in this thesis sought to obtain an overall picture of how strongmen train year-round as such information has more applicability to strength and conditioning coaches and strongman athletes. Future studies should build on this data set and examine how training practices differ at various phase of the year.

6) Finally, longitudinal studies are needed to determine if strongman type exercises are more effective than traditional type gym based approaches at eliciting gains in strength and power. At this time, strength and conditioners advocating the use of

strongman type exercises are doing so without any direct evidence, as no such training studies have been conducted.

Currently, there appears to be an almost complete lack of scientific study into the sport of strongman. Many strength and conditioning practitioners and athletes are using strongman type exercises to enhance athletic performance without any scientific evidence of the benefits and potential risks associated with these exercises. The proposed recommendations will help to inform practice and give new insights and information into the potential benefits and risks associated with strongman training.

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ABBREVIATIONS AND GLOSSARY

ABBREVIATIONS

1RM	One repetition maximum
ATP-PC	Adenosine Triphosphate Phosphocreatine
BB	Bodybuilders
BLa	Blood lactate
BMI	Body mass index
Cir	Circumference
CMJ	Counter movement jump
CMVJ	Counter movement vertical jump
CSA	Cross sectional area
e.d.	Edition
EMG	Electromyography
FFM	Fat free mass
Fm	Maximal force
HIT	High intensity training
HR	Heart rate
MLB	Major league baseball
MM	Muscle mass
NFL	National football league
NHL	National hockey league
NPM	Non-periodised model
OL	Olympic weight lifters
PL	Powerlifters
Pmax	Maximal power output
PP	Peak power

RM	Repetition maximum
RVJ	Relative vertical jump
S&C	Strength and conditioning
SEMG	Surface Electromyography
SJ	Squat jump
SKF	Skinfolds
SPJ	Absolute spike jump
VJ	Vertical jump
Vm	Maximal velocity
VO_2 max	The maximal amount of oxygen a subject can utilise during maximal exercise
Vs	Versus
WHR	Waist hip ratio

UNITS OF MEASUREMENT

bpm	Beats per minute
cm	Centimetre
cm^2	Centimetre squared
CV	Coefficient of variation
ES	Effect size
hrs	Hours
kg	Kilogram
m	Metre
min	Minute
ml.kg.min-1	Milliliters of oxygen used in one minute per kilo of bodyweight.
$mmol.L^{-1}$	Millimols per litre
ms	Millisecond
ms^{-1}	Metres per second
N/kg	Newton (unit of force)/ Kilogram (unit of mass)
r	Correlation coefficient
r^2	Coefficient of determination
SD	Standard deviation
sec	Seconds
SEE	Standard error of the estimate
W	Watts
%	Percentage
%BF	Percentage of body fat

GLOSSARY

Anthropometry	The science of measurement applied to the human body and generally includes measurement of height, weight, and selected body and limb girths.
Aerobic capacity	Describes the functional capacity of the cardiorespiratory system.
Aerobic metabolism	A process that uses oxygen to produce energy in the form of ATP.
Agonists	A muscle that causes specific movement to occur through the process of its own contraction.
Anaerobic endurance	The muscles ability to sustain intense, short duration activity such as weight lifting or sprinting.
Biomechanics	The application of the laws of mechanics to biological systems.
Body composition	The percentages of fat, bone and muscle in human bodies.
Contractile characteristics	The ability of a muscle to produce force, change length and velocity of shortening.
Determinants	Factors that influence or determine performance.
Epidemiology	The study of patterns of health and illness and associated factors at the population level.
Functional movement	In this thesis, functional movements are movements that incorporate a vast amount of musculature and place demand on the body's core musculature and innervation.

Functional performance	In this thesis, functional performance refers to an athlete’s ability to perform sporting activities.
Glycolysis	The metabolic pathway that converts glucose into pyruvate which produces two molecules of ATP.
Hypertrophy training	Training focused on increasing muscle cross sectional area.
Inter-relationships	The relationships between dependant and independent variables.
Isoinertial	The force of a human muscle that is applied to a constant mass in motion.
Kinematics	The characteristics of motion from a spatial and temporal perspective without reference to the forces causing that motion.
Kinetics	The examination of forces acting on a system, such as a human body.
Maximum strength	The maximal amount of force exerted by a voluntary muscle contraction at a specified velocity.
Mechanical advantage	The ease at which the resistance can be moved (e.g. the longer the lever arm of force the less force needed to move the resistance).
Mesomorphy	A somatotype dimension characterised by well-defined skeletal and muscular development.
Morphological adaptations	Involve an increase in cross-sectional area of the whole muscle.

Motor unit firing rate	The rate at which motor neurons discharge action potentials.
Multi-factorial	Involving or including a number of elements or factors.
Muscular endurance	The ability of a muscle or group of muscles to sustain repeated contractions against a resistance for an extended period of time.
Musculoskeletal system	Provides form, stability, and movement to the human body. It consists of the body's bones, muscles, tendons, ligaments, joints, cartilage, and other connective tissue.
Neural adaptations	Are related to an increase in motor unit firing rate and synchronisation.
Periodisation	The variation of training stimuli over periods of time to allow for a proper progression in the exercise stress and planned periods of rest.
Power	The rate at which mechanical work is performed (Power = force x distance/time)
Power training	Training focused on increasing the rate at which force is developed.
Rate of force development	Calculated by dividing peak force by the time taken to reach peak force.
Resistance training	Training that uses a resistance to the force of muscular contraction.

Somatotype	Classification of human physique based on the measurement of body shape and size (i.e. ectomorphic, mesomorphic and endomorphic).
Strength and conditioning coach	A coach whose job is the physical and physiological development of athletes for elite sport performance.
Strength training	The use of resistance to muscular contraction to build the strength.
Strongman competitor	An athlete who competes in strongman competitions.
Synchronisation	The simultaneous or near-simultaneous firing of motor units.
System Force	A variable developed for this thesis, which was determined by: Body mass + 1RM Squat
Torque	The rotational effect of force, and is the product of that force and the perpendicular distance to its line of action.
Unilateral ground reaction force production	The force exerted on the ground from a single leg.
Velocity	The rate of change of displacement with respect to time. Expressed as the ratio of displacement and time (d/t).

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APPENDICES

Appendix 1: Abstracts

Abstracts of descriptive and experimental chapters in review

Winwood, P. W., Keogh, J. W. L., & Harris, N. K. (2010). The strength and conditioning practices of strongman competitors. *Journal of Strength and Conditioning Research, In press (due for publication mid 2011).*

(Chapter 3)

This study describes the results of a survey of the strength and conditioning practices of strongman competitors. A 65-item online survey was completed by 167 strongman competitors. The subject group included 83 local, 65 national and 19 international strongman competitors. The survey comprised 3 main areas of enquiry: a) exercise selection b) training protocols and organisation and c) strongman event training. The back squat and conventional deadlift were reported as the most commonly used squat and deadlift (65.8% & 88.0%, respectively). Eighty percent of the subjects incorporated some form of periodisation in their training. Seventy-four percent of subjects included hypertrophy training, 97% included maximal strength training, and 90% included power training in their training organisation. The majority performed speed repetitions with submaximal loads in the squat and deadlift (59.9 & 61.1% respectively). Fifty-four percent of subjects incorporated lower body plyometrics into their training, and 88% percent of the strongman competitors reported performing Olympic lifts as part of their strongman training. Seventy-eight percent of subjects reported that the clean was the most performed Olympic lift used in their training. Results revealed that 56% and 38% of the strongman competitors used elastic bands and chains in their training, respectively. The findings demonstrate that strongman competitors incorporate a variety of strength and conditioning practices that are focused on increasing muscular size, and the development of maximal strength and power into their conditioning preparation. The farmers walk, log press and stones were the most commonly performed strongman exercises used in a general strongman training session by these athletes. This data provides information into the training practices required to compete in the sport of strongman.

Winwood, P. W., Keogh, J. W. L., Harris, N. K., & Weaver, L. M. (2010). Inter-relationships between strength, anthropometrics, and strongman performance. *Journal of Strength and Conditioning Research, Submitted – in first review.*

(Chapter 4)

The sport of strongman is relatively new hence specific research investigating this sport is currently very limited. The purpose of this study was to determine the relationships between anthropometric dimensions and maximal isoinertial strength to strongman performance in novice strongman athletes. Twenty-three semi-professional rugby union players with considerable resistance training and some strongman training experience (22.0 ± 2.4yr, 102.6 ± 10.8kg, 184.6 ± 6.5cm) were assessed for anthropometry (height, body composition, and girth measurements), maximal isoinertial performance (bench press, squat, deadlift and power clean), and strongman performance (tyre flip, log clean and press, truck pull and farmers walk). The magnitudes of the relationships were determined using Pearson correlation coefficients, and interpreted qualitatively according to Hopkins (Hopkins, 2007) (90% confidence limits ~ ±0.37). The highest relationship observed was between system force (body mass + squat 1RM) and overall strongman performance (r = 0.87). Clear moderate to very large relationships existed between performance in all strongman events and the squat (r = 0.61-0.85), indicating the importance of maximal squat strength for strongman competitors. Flexed arm girth and calf girth were the strongest anthropometric correlates of overall strongman performance (r = 0.79 and 0.70 respectively). The results of this study suggest that body structure and common gym based exercise strength are meaningfully related to strongman performance in novice strongman athletes. Future research should investigate these relationships using more experienced strongman athletes and determine the relationships between changes in anthropometry, isoinertial strength and strongman performance in order to determine the role of anthropometry and isoinertial strength in the sport of strongman.

Appendix 2: Ethics approval form

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: Justin Keogh
From: **Madeline Banda** Executive Secretary, AUTEC
Date: 29 January 2010
Subject: Ethics Application Number 09/296 **Part One: An analysis of the training practices of strongmen and Part Two: The relationship between maximal strength and anthropometrics to strongman performance.**

Dear Justin

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 14 December 2009 and that I have approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 8 February 2010.

Your ethics application is approved for a period of three years until 29 January 2013.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 29 January 2013;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics. This report is to be submitted either when the approval expires on 29 January 2013 or on completion of the project, whichever comes sooner;

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

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Paul Winwood p.winwood@yahoo.co.nz, Nigel Harris

Appendix 3: Strongman Training Practices Questionnaire

The purpose of this questionnaire is to gather information on the training practices of strongman competitors. The information will be used to produce an academic report detailing the training practices of strongman competitors. All information and results will be kept confidential and anonymous. By completing this questionnaire you will be giving your consent to participate in this research.

Section 1: Demographics

1) **GENDER: --**
2) **AGE (years):** ---
3) **HEIGHT (cm):** ---
4) **COUNTRY OF ORIGIN:** ---
5) **REGULAR COMPETITION WEIGHT (kg):** ---
6) **WEIGHT TRAINING EXPERIENCE (years):** --
7) **STRONGMAN TRAINING EXPERIENCE (years):** ---
8) **HIGHEST COMPETITION LEVEL YOU HAVE COMPETED AT? (i.e. local, national or international competitor)**

BEST LIFTS: What were your best lifts within the last year? (Please state weight in kg for your 1RM. You can include lifts in which you used a lifting belt, but DO NOT INCLUDE lifts when you used bench shirts, squat/deadlift suits or knee wraps. <u>If you haven't performed 1RM lifts in the last year, please write in your heaviest weight lifted and how many reps you performed with that weight.</u>

9) **SQUAT:** --

   DEADLIFT: --

   BENCH PRESS: --

   POWER CLEAN: --

   PUSH PRESS: --

Section 2: Exercise selection

10) Do you perform traditional resistance exercises like the squat, deadlift and bench press as part of your training? (If you don't perform traditional gym based resistance exercises please go to section 3).

Yes	No
◯	◯

11) What type of **squats** do you commonly use in your training?

	Do not perform	Very rarely perform	Sometimes perform	Quite often perform	Most commonly performed
Back Squats	0	1	2	3	4
Front Squats	0	1	2	3	4
Box Squats	0	1	2	3	4
Zercher Squats	0	1	2	3	4

12) What type of **deadlifts** do you commonly use in your training?

	Do not perform	Very rarely perform	Rarely perform	Sometimes perform	Quite often perform	Most commonly performed
Conventional	0	1	2	3	4	5
Sumo/SemiSumo	0	1	2	3	4	5
Romanian	0	1	2	3	4	5
Partial	0	1	2	3	4	5
Deficit/box	0	1	2	3	4	5

Section 3: Training protocols and organisation

Periodisation is the process in which there is planned variation in the exercise programme (e.g. exercises performed, sets, reps, rest periods etc) either within a weekly training cycle and/or across many weeks of training. It is used in many sports to achieve peak performance in a select number of competitions each year.

13) Do you use some form of **periodisation** in your training?

Yes ○ No ○

14) Do you use some form of training **log** or training **diary** in your training?

Yes ○ No ○

Section 3.1: Gym based hypertrophy training (i.e. training directly focused on building muscle size and mass)

15) Do you do any **hypertrophy** training? (If your answer is no, please go to section 3.2)

Yes ○ No ○

16) Do you normally perform your hypertrophy training to failure, close to failure or not to failure?

Failure ○ Close to failure ○ Not to failure ○

17) Typically, how many **repetitions** do you perform in each set as part of your **hypertrophy** training?

1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○

8 ○ 9 ○ 10 ○ 11 ○ 12 ○ 13 ○ 14 ○ 15+ ○

18) Typically, how many **sets** do you perform for each exercise as part of your **hypertrophy** training?

1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○

8 ○ 9 ○ 10 ○ 11 ○ 12 ○ 13 ○ 14 ○ 15+ ○

19) Typically, how long are your **rest** periods between sets in your **hypertrophy** training?

<1min ○ 1-2min ○ 2-3min ○ 3-4min ○ >4min ○

Section 3.2: Gym based strength training (i.e. training directly focused on increasing one repetition maximum strength)

20) Do you do any maximal **strength** training? (If your answer is no please go to section 3.3)

Yes ○ No ○

21) Typically, how many **repetitions** do you perform in each set as part of your maximal **strength** training?

1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○

8 ○ 9 ○ 10 ○ 11 ○ 12 ○ 13 ○ 14 ○ 15+ ○

22) Typically, how many **sets** do you perform for each exercise as part of your maximal **strength** training?

1	2	3	4	5	6	7	
○	○	○	○	○	○	○	
8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

23) Typically, how long are your **rest** periods between sets in your maximal **strength** training?

<1min	1-2min	2-3min	3-4min	>4min
○	○	○	○	○

Section 3.3: Strength/power training methods (i.e. training directly focused on increasing explosive strength and power)

24) Once warmed up do you perform your traditional resistance exercise repetitions:

As fast as possible (maximum)	At speeds less than maximum	Mixture of maximum & less than maximum
○	○	○

25) During your training do you ever perform the **squat** at maximum speed with weights at or lower than 70% of your maximum (1RM)? I.e. "**speed squats**."

Yes	No
○	○

26) If you answered yes to question 15, what loads (as a % of your maximum) do you use to perform your **speed squats**? (Please select more than one if appropriate.)

0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%
○	○	○	○	○	○	○

27) During your training do you ever perform the **deadlift** at maximum speed with weights at or lower than 70% of your maximum (1RM)? I.e. “**speed deadlift**.”

Yes	No
◯	◯

28) If you answered yes to question 17, what loads (as a % of your maximum) do you use to perform your **speed deadlifts**? (Please select more than one if appropriate.)

0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%
◯	◯	◯	◯	◯	◯	◯

29) Do you ever include **elastic bands** as part of your training? (Please select more than one if appropriate).

No	Yes for the Squat	Yes for Upper Body Press *	Yes for the Deadlift	Yes for Assistance Exercises
◯	◯	◯	◯	◯

* Upper body press includes bench press, shoulder press etc

30) Do you ever include **chains** as part of your training? (Please select more than one if appropriate).

No	Yes for the Squat	Yes for Upper Body Press *	Yes for the Deadlift	Yes for Assistance Exercises
◯	◯	◯	◯	◯

* Upper body press includes bench press, shoulder press etc

31) Do you ever include **Olympic** weight training lifts as part of your training? (Please select more than one if appropriate).

No	Yes the Clean	Yes the Snatch	Yes the Jerk	Yes the high Pull
◯	◯	◯	◯	◯

32) If you answered yes to question 21. What **loads** (as a % of your maximum) do you most normally train with for your **Olympic** lifting?

10%-20% ◯ 20%-30% ◯ 30%-40% ◯ 40%-50% ◯ 50%-60% ◯ 60%-70% ◯ 70%-80% ◯

80%-90% ◯ 90%-100% ◯

33) Do you ever include **ballistic** training (i.e. weighted squat jumps or bench press throws) as part of your training?

Yes ◯ No ◯

34) If you answered yes to question 23. What **loads** (as a % of your maximum) do you most normally train with for your **ballistic** lifting?

10%-20% ◯ 20%-30% ◯ 30%-40% ◯ 40%-50% ◯ 50%-60% ◯ 60%-70% ◯ 70%-80% ◯

80%-90% ◯ 90%-100% ◯

35) Do you ever include **lower body** plyometric drills (i.e. explosive bounding and jumping) as part of your training?

Yes ◯ No ◯

36) Do you ever include **upper body** plyometric drills (i.e. rebound medicine ball throws) as part of your training?

Yes ◯ No ◯

37) Typically, how many **repetitions** do you perform in each set as part of your **power** training?

1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 ◯ 6 ◯ 7 ◯

8 ◯ 9 ◯ 10 ◯ 11 ◯ 12 ◯ 13 ◯ 14 ◯ 15+ ◯

38) Typically, how many **sets** do you perform for each exercise as part of your **power** training?

1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 ◯ 6 ◯ 7 ◯

8 ◯ 9 ◯ 10 ◯ 11 ◯ 12 ◯ 13 ◯ 14 ◯ 15+ ◯

39) Typically, how long are your **rest** periods between sets in your **power** training?

<1min ◯ 1-2min ◯ 2-3min ◯ 3-4min ◯ >4min ◯

Section 3.4: Aerobic/anaerobic conditioning

40) Does your strongman training include **aerobic/anaerobic** conditioning? (If your answer is no, please go to section 4)

Yes ◯ No ◯

41) Typically, how long are your training sessions for your **aerobic/anaerobic** conditioning?

< 15min	16- 30min	31-45min	46-60 min	> 60 min
○	○	○	○	○

42) What sort of **aerobic/anaerobic** conditioning do you perform as part of your strongman training?

	Do not perform	Very rarely perform	Sometimes perform	Quite often perform	Most commonly performed
Low Intensity Cardio	0	1	2	3	4
High Intensity Cardio Interval Training	0	1	2	3	4
A combination of the Two	0	1	2	3	4
Other Conditioning	0	1	2	3	4

Section 4: Strongman Training

(This section is specifically strongman training only and covers strongman implements used in training).

43) How do you normally incorporate **strongman training implements** into your strongman training?

Use strongman implements only   Mix gym work and strongman implements together

○ ○

44) Typically, how many **sessions** per week do you perform specifically using strongman implements?

1	2	3	4	5	6	7 or more
○	○	○	○	○	○	○

45) Typically, how many training **sessions** per week would you perform the **tyre flip**?

<1*	1	2	3	4	5	6 or more
○	○	○	○	○	○	○

<1* Means you may perform only once per fortnight

46) Typically, how many **sets** of the **tyre flip** would you perform in a training session?

1	2	3	4	5	6	7	
○	○	○	○	○	○	○	
8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

47) Typically, how many **repetitions** of the **tyre flip** do you perform in a training session?

1	2	3	4	5	6	7	
○	○	○	○	○	○	○	
8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

48) Typically, when training for the **tyre flip** do you train with loads lighter, the same or heavier as those you would do in competition?

Lighter	The same	Heavier
○	○	○

49) Typically, how many training **sessions** per week would you perform the **log press**?

<1*	1	2	3	4	5	6 or more
○	○	○	○	○	○	○

<1* Means you may perform only once per fortnight

50) Typically, how many **sets** of the **log press** would you perform in a training session?

1	2	3	4	5	6	7
○	○	○	○	○	○	○

8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

51) Typically, how many **repetitions** of the **log press** do you perform in a training session when training for a competition that has log press for repetitions in it?

1	2	3	4	5	6	7
○	○	○	○	○	○	○

8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

52) Typically, when training for a competition involving **log press** for repetitions, do you train the log press with loads lighter, the same or heavier as those you would do in competition?

Lighter	The same	Heavier
○	○	○

53) Typically, how many training **sessions** per week would you perform the **stones**?

<1*	1	2	3	4	5	6 or more
○	○	○	○	○	○	○

<1* Means you may perform only once per fortnight

54) Typically, how many **sets** of the **stones** would you perform in a training session?

1	2	3	4	5	6	7
○	○	○	○	○	○	○

8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

55) Typically, how many **repetitions** of the **stones** do you perform in a training session?

1	2	3	4	5	6	7
○	○	○	○	○	○	○

8	9	10	11	12	13	14	15+
○	○	○	○	○	○	○	○

56) Typically, when training for the **stones** do you train with loads lighter, the same or heavier as those you would do in competition?

Lighter	The same	Heavier
○	○	○

57) Typically, how many training **sessions** per week would you perform the **farmers walk**?

<1*	1	2	3	4	5	6 or more
○	○	○	○	○	○	○

<1* Means you may perform only once per fortnight

58) Typically, when training for the **farmers walk** what sort of **distance** do you cover as a working set for your strongman training?

10m	20m	30m	40m	50m	60m	70m or more
○	○	○	○	○	○	○

59) Typically, when training for the **farmers walk** do you train with loads lighter, the same or heavier as those you would do in competition?

Lighter	The same	Heavier
○	○	○

60) Typically, how many training **sessions** per week would you perform the **truck pull**?

<1*	1	2	3	4	5	6 or more
○	○	○	○	○	○	○

<1* Means you may perform only once per fortnight

61) Typically, when training for the **truck pull** what sort of **distance** do you cover as a working set for your strongman training?

10m	20m	30m	40m	50m	60m	70m or more
○	○	○	○	○	○	○

62) Typically, when training for the **truck pull** do you train with loads lighter, the same or heavier as those you would do in competition?

Lighter	The same	Heavier
○	○	○

63) Typically, how long are your **rest** periods between sets in your **strongman** training?

<1min	1-2min	2-3min	3-4min	>4min
○	○	○	○	○

64) What other strongman **type implements** do you use on a frequent basis? (Please select more than one if appropriate).

Sandbags	Sleds	Axle	Yoke	Kegs
◯	◯	◯	◯	◯

Other (please name)

___

65) Is there anything that you wish to add?

___

Thank you for your assistance

Appendix 4: Participant Information Letter

Strongman Training Practices Survey

Hello, strongman competitors. Thank you for your time to undertake this survey. My name is Paul Winwood and I have competed in bodybuilding and powerlifting, and have a passion for resistance training. This survey will form part of my masters thesis, which is under the guidance of my primary supervisor Justin Keogh, PhD (<105kg 2008 New Zealand strongman winner).

The purpose of this survey is to gain some insight into the common training practices of strongman competitors.

To be eligible to be part of this survey you must fit the following inclusion criteria: Participants must be current professional or amateur strongman competitors; they must have competed in a strongman competition or are in-training for their first strongman competition; and be male between the ages of 18 to 45 years.

This study will help improve our understanding of training practices for the sport of strongman as well as differences in training practices between elite and sub-elite competitors. The information could also help guide future competitors in how they should train for the sport of strongman.

The following survey is divided into 4 Sections. Section 1 (demographics); Section 2 (exercise selection); Section 3 (training protocols and organisation); and Section 4 (strongman training).

Please answer all questions. The survey is quite comprehensive and while everyone is different, this questionnaire would appear to take about 12-20 minutes to complete. By completing this questionnaire you will be giving your consent to participate in this research.

Appendix 5: Participant Information Letter

Project title: The Relationship of Maximal strength and Anthropometrics to Strongman Performance

My name Paul Winwood and I am a full time staff member at the Bay of Plenty Polytechnic and am a student at the Auckland University of Technology. I have competed in bodybuilding and powerlifting, and have a passion for resistance training, and I have trained regularly for over five years. I would like you to be a participant in this research. Your participation is entirely voluntary and you may withdraw from this research at any time without adverse consequences. This project has been designed to fit in with your pre-season maximal strength and functional performance testing.

The purpose of this research is to determine the relationship of maximal strength and anthropometrics to functional performance. This experimental research will form part of my Masters thesis and contribute towards my Masters degree. Journal articles and conference presentations on this data set will also be sought.

You have been selected, as you are a professional rugby player, familiar with maximal strength testing and you have competed in a strongman event. The inclusion criteria for this project are: resistance training experience (> 3 times per week) for more than two years before the start of this study. Participants must have taken part in the 2009 North Harbour rugby teams strongman competition or performed strongman training in the North Harbours rugby training sessions.

You will be required to perform anthropometric and strength assessments.
Height, body mass, fat free mass, % body fat, and girth and limb measurements will be assessed by the primary supervisor, qualified with the International Society for the Advancement of Kinanthropometry.

Maximal strength testing will include the bench press, squat, deadlift and power clean. You will also be required to perform strongman performance testing in the tyre flip, zercher carry, log press, farmers walk, heavy sled and/or truck pull.

There are physical risks involved in this project, as you will be performing at maximal intensity. However, risks will be minimised with adequate warm up and cool down protocols. You will receive a familiarisation session whereby a demonstration of correct technique will be provided by two experienced powerlifters, and safety protocols will be discussed and implemented. The experienced powerlifters will be critiquing technique during testing to ensure you maintain proper form to avoid possible injury.

As a participant in this study you will receive an anthropometric profile as part of your testing. This will give you an indication of your body structure (amount of muscle mass and body fat percentage), this could help you determine what your optimal body structure should be in relation to normative data and your position of play.

The results of this study could also benefit the sport of rugby in general. If a relationship between maximal strength and anthropometrics to functional performance exists, strength and conditioners will be able to prescribe more efficient training programmes.

The results could also lead to a talent identification battery for rugby based on maximal strength data and easily obtained antropometric characteristics. This may allow coaches and administrators involved in the sport of rugby to search for and identify potential players for their teams.

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

Your privacy will be protected. All information is confidential, and only the researcher and research supervisors will have access to data collected. Hard copies of the data will be stored in a secure room at AUT and electronic data will be stored on password-protected computers accessed by the researcher and supervisors. The dissemination of data will not identify you in any way.

You will be required for two days of testing for this project. On day one you will perform anthropometric and maximal strength testing, and functional testing on another day within a 2-week period.

You will have the opportunity of two weeks to consider this invitation. If you do wish to be part of this research please fill in the attached informed consent form. If you wish to receive feedback on the results of this research you could tick the box on the informed consent form that you wish to receive a copy of the report or contact the researcher by email from the address below.

If you have any concerns regarding the nature of this project please notify the project supervisor: Justin Keogh, justin.keogh@aut, Ph 921 9999 ext 7617

If you have any concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, madeline.banda@aut.ac.nz, Ph 921 9999 ext 8044.

For further information about this research contact:

Researcher Contact Details:
Paul Winwood, p.winwood@yahoo.co.nz***, Ph 08002677659 ext 6778***

Approved by the Auckland University of Technology Ethics Committee on 22 December 2009 **AUTEC Reference number** 09/296.

Appendix 6: Informed Consent Form

Project title: The Relationship of Maximal strength and Anthropometrics to Strongman Performance

Project Supervisor: Justin Keogh

Researcher: Paul Winwood

- ○ I have read and understood the information provided about this research project in the participant information letter
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that my data will be recorded during testing for research purposes only
- ○ I understand that taking part in this study is voluntary, and that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way. If I withdraw, I understand that all my relevant information will be destroyed.
- ○ I understand that my participation in this study is confidential and that no material, which could identify me, will be used in any reports on this study.
- ○ I have been verbally informed and fully understand the procedures and potential risks of the tests in which I am a subject.
- ○ I agree to take part in this research.
- ○ I wish to receive a copy of the report from the research (please tick one):

  Yes ○ No ○

Participant's signature:
....

Participant's name:
....

Participant's Contact Details (if appropriate):
……………………………………………………………………………………..
……………………………………………………………………………………..
……………………………………………………………………………………..
……………………………………………………………………………………..
Date:

Approved by the Auckland University of Technology Ethics Committee on 22 December 2009 **AUTEC Reference number** 09/296.

Appendix 7: Swinton et al. (2009) Powerlifting survey

Personal information and results will be kept confidential and anonymous. The purpose of this information is solely to produce an academic report detailing the training practices of top level powerlifters.

NAME: ---
DATE OF BIRTH: ---
WEIGHT CLASS: --
Email: ---

1) Once warmed up do you perform your **squat** repetitions:

As fast as possible (maximum)	At speeds less than maximum	Mixture of maximum & less than maximum
◯	◯	◯

2) Once warmed up do you perform your **bench press** repetitions:

As fast as possible (maximum)	At speeds less than maximum	Mixture of maximum & less than maximum
◯	◯	◯

3) Once warmed up do you perform your **deadlift** repetitions:

As fast as possible (maximum)	At speeds less than maximum	Mixture of maximum & less than maximum
◯	◯	◯

4) During your training do you ever perform the **squat** at maximum speed with weights at or lower than 70% of your maximum (1RM)? I.e. "**speed squats**."

Yes	No
◯	◯

5) If you answered yes to question 4, what loads (as a % of your maximum) do you use to perform your **speed squats**? (Please select more than one if appropriate.)

0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%
◯	◯	◯	◯	◯	◯	◯

6) During your training do you ever perform the **bench press** at maximum speed with weights at or lower than 70% of your maximum (1RM)? i.e. "**speed bench press**."

Yes	No
◯	◯

7) If you answered yes to question 6, what loads (as a % of your maximum) do you use to perform your **speed bench presses**? (Please select more than one if appropriate.)

0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%
○	○	○	○	○	○	○

8) During your training do you ever perform the **deadlift** at maximum speed with weights at or lower than 70% of your maximum (1RM)? I.e. "**speed deadlift**."

Yes	No
○	○

9) If you answered yes to question 8, what loads (as a % of your maximum) do you use to perform your **speed deadlifts**? (Please select more than one if appropriate.)

0-10%	10-20%	20-30%	30-40%	40-50%	50-60%	60-70%
○	○	○	○	○	○	○

10) Do you ever include lower body plyometric drills (i.e. explosive jumping) as part of your power lifting training?

Yes	No
○	○

11) Do you ever include upper body plyometric drills (i.e. rebound medicine ball throws) as part of your power lifting training?

Yes	No
○	○

12) Do you ever include Olympic weight training lifts as part of your power lifting training? (Please select more than one if appropriate.)

No	Yes the Clean	Yes the Snatch	Yes the Jerk	Yes the high Pull
○	○	○	○	○

13) Do you ever include elastic bands as part of your powerlifting training? (Please select more than one if appropriate.)

No	Yes for the Squat	Yes for the Bench Press	Yes for the Deadlift	Yes for Assistance Exercises
○	○	○	○	○

14) Do you ever include chains as part of your powerlifting training? (Please select more than one if appropriate.)

No	Yes for the Squat	Yes for the Bench Press	Yes for the Deadlift	Yes for Assistance Exercises
○	○	○	○	○

15) Do you perform box squats as part of your powerlifting training?

No	Yes, less than Free Squats	Yes, the same as Free Squats	Yes, more than Free Squats
○	○	○	○

16) Do you ever use "boards" when bench pressing as part of your powerlifting training?

Yes	No
○	○

17) Do you use some form of periodisation in your organising powerlifting training?

Yes	No
○	○

18) What assistance exercise do you believe best improves your **squat**?

----

19) What assistance exercise do you believe best improves your **bench press**?

----

20) What assistance exercise do you believe best improves your **deadlift**?

Please sign here to acknowledge that you have granted permission for your results to be included in an academic report.

Thank you for your assistance

Appendix 8: Summaries of literature on the anthropometry of males in the weight-lifting sports.

Table 14: Summary of the literature on the anthropometry of male weightlifters (mean ± SD).

Study	**Participants**	**Height (cm)**	**Body mass (kg)**	**Body composition (%)**	**Fat-free mass (kg)**
Sprynarova and Parizkova (1971)	14 elite weightlifters	166.36 ± 7.08	77.17 ± 14.91	9.84 ± 5.18	90.16 ± 5.18
Katch et al. (1980)	8 sub-elite	173.9 ± 1.8SEM	76.5 ± 3.7SEM	10.8 ± 0.85[a]SEM	68.2 ± 3.2SEM
Marchocka and Smuk (1984)	3 elite up to 52kg	151.6	54.5	N.S.	43.2
	3 elite up to 56kg	158.4	57.7	N.S.	52.4
	5 elite up to 60kg	158.3	61.6	N.S.	55.5
	4 elite up to 67.5kg	164.5	69.8	N.S.	62.8
	1 elite up to 75kg	171.0	74.8	N.S.	67.9
	2 elite up to 82.5kg	171.0	80.5	N.S.	73.3
	3 elite up to 90kg	175.0	88.0	N.S.	79.5
	3 elite up to 100kg	176.7	100.0	N.S.	85.2
	2 elite above 100kg	183.6	131.7	N.S.	103.6

Pilis et al (1997)	12 elite below 60kg	159.75 ± 4.90	56.24 ± 3.4	8.54 ± 2.00[b]	51.14 ± 3.40
	8 elite between 60.1 & 75.0kg	165.13 ± 5.00	71.80 ± 3.60	9.78 ± 3.43[b]	64.76 ± 4.52
	10 elite between 75.1 & 90.0kg	175.30 ± 5.54	84.21 ± 3.91	9.80 ± 3.79[b]	75.08 ± 3.64
	14 elite above 90kg	179.79 ± 4.98	102.31 ± 6.87	16.55 ± 3.78[b]	85.52 ± 4.62
McBride et al. (1999)	6 elite weightlifters	172.0 ± 2.9	85.3 ± 9.5	10.4 ± 2.8[c]	N.S.
Stone et al. (2005)	9 elite weightlifters	171.0 ± 5.3	95.2 ± 19.0	N.S.	80.5 ± 11.8
Fry et al. (2006)	20 elite junior weightlifters	N.S.	67.3 ± 10.4	6.4 ± 2.9[a]	63.7 ± 8.4
	95 nonelite junior weightlifters	N.S.	62.3 ± 16.5	10.3 ± 7.1[a]	55.0 ± 13.2

Note: Body composition is body fat percentage unless indicated otherwise.
Key: The Σ6SF was the sum of the triceps, subscapular, chest, suprailliac, thigh, and calf skinfolds. Body fat percentage calculated by the following methods: [a]hydrostatic weighing and Siri (1956); [b]Durnim and Womersley (1974); [c]Jackson and Pollock (1977). Fat free mass was calculated by subtracting the fat mass (as estimated from the respective equations) from total body mass. SEM = standard error from the mean. N.A. = not assessed. N. S. = not stated

Table 15: Summary of the literature on the anthropometry of male powerlifters (mean ± SD).

Study	Participants	Height (cm)	Body mass (kg)	Body composition (% or as stated)	Fat-free mass (kg)
Katch et al. (1980)	13 sub-elite to elite	173.5 ± 2.8SEM	80.8 ± 3.2SEM	9.1 ± 1.2[a]SEM	73.3 ± 2.7SEM
Mayhew et al. (1993a)	99 adolescent novice	173.6 ± 7.3	74.1 ± 16.5	Σ6SF=73.7 ± 30.1mm	N.A.
Fort et al. (1996)	9 elite lightweight	160.4 ± 4.8	< 67.5kg	9.6 ± 2.5[b]	N.S.
	6 elite middleweight	172.1 ± 6.0	67.5-82.5kg	12.6 ± 3.1[b]	N.S.
	9 elite heavyweight	174.9 ± 4.7	> 82.5kg	16.2 ± 3.4[b]	N.S.
McBride et al. (1999)	8 elite	173.9 ± 1.4	78.2 ± 3.7	8.7 ± 1.3[c]	N.S.
Dickermann et al. (2000)	1 world record holder	177.0	109.0	14.0[g]	N.S.
Brechue and Abe	7 elite lightweight	159.9 ± 5.0	63.9 ± 5.6	13.7 ± 2.2[d]	52.2 ± 5.3

(2002)	6 elite middleweight	166.1 ± 5.7	78.4 ± 6.7	14.4 ± 2.1[d]	67.0 ± 5.0
	7 elite heavyweight	181.6 ± 6.6	135.1 ± 26.5	26.7 ± 7.1[d]	97.7 ± 10.9
Keogh et al. (2005)	42 sub-elite to elite	172.0 ± 8.0	91.0 ± 21.0	15.0 ± 5.0[e]	77.0 ± 13.0
Keogh et al. (2007)	9 elite lightweight	163.0 ± 7.2	68.9 ± 7.9	From Σ6SF= 13.7 ± 6.8 [f]	62.3 ± 6.0
	30 elite middleweight	174.7 ± 4.9	87.7 ± 6.9	From Σ6SF= 14.3 ± 3.4 [f]	79.2 ± 5.0
	15 elite heavyweight	174.7 ± 9.6	121.9 ± 17.2	From Σ6SF= 24.7 ± 6.2 [f]	106.5 ± 12.9
Keogh et al. (2009a)	17 weaker sub-elite to elite	174.2 ± 7.2	88.7 ± 13.9	From Σ6SF= 15.8 ± 5.8[f]	N.S.
	17 stronger sub-elite to elite	170.3 ± 7.8	94.9 ± 23.7	From Σ6SF= 16.5 ± 7.2[f]	N.S.

Note: Body composition is body fat percentage unless indicated otherwise.
Key: The Σ6SF was the sum of the triceps, subscapular, chest, suprailliac, thigh, and calf skinfolds. Body fat percentage calculated by the following methods: [a]hydrostatic weighing and Siri (1956); [b]not stated; [c]Jackson and Pollock (1977). [d]ultrasound and Brozek et al. (1963); [e]Sloan and Weir (1970); [f]Withers et al. (1987); [g]Dexa scan. Fat free mass was calculated by subtracting the fat mass (as estimated from the respective equations) from total body mass. SEM = standard error from the mean. N. S. = not stated.

Table 16: Summary of the literature on the anthropometry of male bodybuilders (mean ± SD).

Study	Participants	Height (cm)	Body mass (kg)	Body composition (% or as stated)	Fat-free mass (kg)
Spitler et al. (1980)	10 sub-elite to elite	179.3 ± 6.1	91.3 ± 8.9	9.9 ± 1.9[b]	N.S.
Tesch & Larsson (1982)	3 sub-elite	177.0	84.0	4.0[c]	N.S
Elliot et al. (1987)	16 non-elite	175.0 ± 8.0	76.0 ± 6.0	7.2 ± 3.3[d]	N.S.
Fry et al. (1987)	12 bodybuilders	174.26 ± 8.26	81.24 ± 13.96	From Σ7SF= 8.48 ± 3.90	N.S.
	9 bodybuilders	178.72 ± 34.37	86.1 ± 9.5	5.91 ± 3.22[b], 4.93 ± 1.12[d], 11.76 ± 3.16[f]	81.13 ± 10.39[b], 81.85 ± 9.09[d], 76.07 ± 9.63[f]
Fry et al. (1991)	36 non-elite	174.4 ± 6.7	80.3 ± 11.0	9.3 ± 1.6[b]	72.8 ± 9.8

Bamman et al. (1993)	6 bodybuilders	173.6	Wk12: 91 ± 4.4 Wk 9: 89.3 ± 3.6 Wk6: 87.5 ± 3.7 Wk3: 86.0 ± 3.0 Wk0: 83.7 ± 2.0	Wk12: 9.1 ± 1.2[e] Wk 9: 7.4 ± 1.5[e] Wk6: 6.6 ± 1.4[e] Wk3: 5.3 ± 1.4[e] Wk0: 4.1 ± 1.3[e]	Wk12: 82.7 ± 3.6 Wk 9: 82.7 ± 2.8 Wk6: 81.6 ± 2.6 Wk3: 81.4 ± 1.9 Wk0: 80.3 ± 1.2
Huygens et al.(2002)	34 bodybuilders	175.1 ± 6.6	86.0 ± 11.5	Σ10SF=64.1 ± 17.9mm	N.S.
Van Marken Lichtenbelt et al. (2004)	27 bodybuilders	176.0 ± 7.6	79.7 ± 10.7	16.7 ± 4.1[a]	66.2 ± 8.4

Note: Body composition is body fat percentage unless indicated otherwise.
Key: The Σ10SF was the sum of the biceps, biceps medial, triceps, forearm lateral and medial, subscapular, chest, supra-illiac, front thigh, and calf medial and lateral. The Σ7SF was taken from the triceps, scapular, abdominal, supra-illiac, mid-axillary, juxta-nipple, and thigh. Body fat percentage calculated by the following methods: [a]Siri (1956); [b]Brozek et al. (1963); [c]Hermansen & von Dobeln (1971); [d]Jackson and Pollock (1977); [e]Durnim and Womersley (1974); [f] Body composition analyser (Model BIA-103B). Fat free mass was calculated by subtracting the fat mass (as estimated from the respective equations) from total body mass. SEM = standard error from the mean. Wk = week; Wk0 = week of competition. N. S. = not stated.

Appendix 9: Summaries of literature showing sprint and jump performance relationships with isoinertial tests of lower body strength and power.

Table 17: The relationship between sprint performance and isoinertial tests of lower body strength and power.

Study	Subjects	Sprint Performance Measure	Strength Measure	Pearson Correlation Coefficient	Power Measure	Pearson Correlation Coefficient
Baker & Nance (1999)	20 professional rugby league players	10m time	3RM Full squat 3RM squat/ kg body mass	-0.06 -0.39	Jump squat mean power (W) Jump squat mean power (W/kg)	-0.02 to –0.08 -0.52 to –0.61
		40m time	3RM Full squat 3RM squat/ kg body mass	-0.19 -0.66	Jump squat mean power (W) Jump squat mean power (W/kg) (at loads of 40, 60, 80 and 100 kg)	-0.02 to -0.17 -0.52 to –0.76
Cronin & Hansen (2005)	26 male professional rugby league players	5m time 10m time 30m time	3RM parallel squat	-0.05 -0.01 -0.29	Jump squat (30kg) average power (W)	-0.13 -0.11 0.15
Harris et al. (2008)	30 national male rugby players	10m time 30/40m time	Squat Machine	0.20 -0.14	Jump squat kinetic measures (W) Jump squat kinetic measures (W/kg) (at loads of 20, 30, 40, 50, 60, 70 80 and 90 kg)	0.32 to 0.53 0.01 to 0.29

						-0.72
						-0.73
Maulder et al. (2006)	10 male national and regional sprinters	10m time			Jump squat mean power (W/kg)	-0.79
					Jump squat peak power (W/kg)	-0.77
					CMJ mean power (W/kg)	
					CMJ peak power (W/kg)	
McBride et al. (2009)	17 Division I-AA male football athletes	5 yard time	1RM Squat/Body mass Index	-0.45		
		10yard time		-0.54*		
		40yard time		-0.61*		
Chelly et al. (2010)	23 male regional-level soccer players	Velocity first 5m ($m.s^{-1}$)	1RM half squat	0.66*	Jump squat mean power (W)	0.45*
					Jump squat mean power (W/kg)	0.43*
					CMJ mean power (W)	0.34
					CMJ mean power (W/kg)	0.28
Wisloff et al. (2004)	17 international male soccer players	10m time	1RM half squat	0.94*	Vertical jump (height)	0.72
		30m time		0.71*		0.60
Young et al. (1995)	11 male & 9 female track & field athletes	Maximum speed			Force at 100ms (N/kg body mass)	-0.80
		50m time			Average power (N/kg body mass)	-0.79
					CMJ	-0.77

Key: RM – Repetition maximum, CMJ – Counter movement jump.

Table 18: The relationship between jumping performance and isoinertial tests of lower body strength and/or power.

Study	Subjects	Jump Performance Measure	Strength/power Measure	Pearson Correlation Coefficient
Blackburn et al. (1998)	20 female physiotherapy students	Vertical jump height (m)	1RM machine squat	0.72*
		Standing long jump (m)		0.65*
Nuzzo et al. (2008)	12 Division A male football and track and field athletes	CMVJ height	1RM squat	0.22
			Squat 1RM relative (kg/kg)	0.69*
			1RM power clean	0.06
			Power clean relative (kg/kg)	0.64*
Peterson et al. (2006)	19 men and 36 woman college athletes	CMVJ height (m)	1RM back squat	0.86*
		CMVJ PP (W)		0.92*
		Horizontal standing broad jump (m)		0.77*
Requena et al. (2009)	21 male 1st division soccer players	CMVJ height (m)	1RM half squat	0.50*
		Squat vertical jump height (m)		0.50*
Stone et al. (2003)	22 male subjects	CMVJ and SJ power (W)	1RM squat	0.77* to 0.94*

Sheppard et al. (2008)	21 national volleyball players	Relative CMVJ height (m)	Max relative Power clean Max relative parallel squat	0.53* 0.54*
Thomas et al. (1996)	19 healthy women	Vertical jump height (m)	Double leg press peak power (W) Wingate test (PP)	0.73* 0.55*
Wisloff et al. (2004)	17 international male soccer players	Vertical jump height (m)	1RM half squat (kg)	0.78*

Key: 1RM – One repetition maximum, CMVJ – Counter movement vertical jump, SJ – Squat jump, PP – Peak power