STRONGMAN IMPLEMENT TRAINING: APPLICATIONS FOR STRENGTH AND CONDITIONING PRACTICE

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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 Doctor of Philosophy guidelines by constructively critiquing previous literature pertinent to the use of strongman implements in strength and conditioning practice. 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 fulfillment of the degree of Doctor of Philosophy.

Articles In-Press or Under Review

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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 reports and papers, as well as being the main 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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ABSTRACT

In recent years, the use of strongman training modalities for performance enhancement have become popular in strength and conditioning practice. While advocates of strongman training have suggested strongman implement training is more specific than other forms of strength training and may help ‘bridge’ the gap between gymnasium-based strength training and functional performance, little information exists in the scientific literature as to the risks and benefits of strongman implement training. This thesis sought to investigate the possible injury risks and benefits of strongman implement training in strength and conditioning practice.

In study one, a survey was used to determine how strength and conditioning coaches utilised strongman training implements in their strength and conditioning practice. It was found that eighty-eight percent (n = 193) of coaches used strongman implements in the training of their athletes, with sleds, ropes, kettlebells, tyres, sandbags and farmers walk bars ranked as the top six implements used. Anaerobic/metabolic conditioning, explosive strength/power and muscle endurance were the three main physiological reasons for strongman implement use.

Study two was undertaken to determine the injury epidemiology of strongman athletes. Eighty two percent of strongman athletes reported injuries (1.6 ±1.5 training injuries/lifter/y, 0.4 ±0.7 competition injuries/lifter/y, 5.5 ±6.5 training injuries/1000 hr training) with the highest reported areas of injury being lower back (24%), shoulder (21%), bicep (11%) and knee (11%). The most common type of injuries was strains and tears of muscle (38%) and tendon (23%). An interesting finding from this study was that although 54% of injuries resulted from traditional training, strongman athletes were 1.9 times more likely to sustain injury when performing strongman implement training when exposure to the type of training was considered.

Studies three, four and five compared the biomechanical characteristics of three strongman exercises (farmers walk, heavy sprint style sled pull and log lift) with three traditional exercises (deadlift, squat and clean and jerk), respectively. These studies gave insight into the potential stresses associated with strongman training implements and the likely chronic adaptations associated with training with these implements. The kinetic data presented on the strongman and traditional exercises provided the necessary information to help accurately equate loading in the final training study.

The final study presented in this thesis compared the effects of seven weeks of strongman resistance training versus traditional resistance training. Thirty experienced resistance-trained rugby players were assessed for body composition, strength, power, speed and change of direction (COD) measures. The main findings were that all performance measures improved with training (0.2% to 7.0%) in both the strongman and traditional training groups, however no significant between-group differences were observed in functional performance measures after 7-weeks of resistance training. Between group differences indicated small positive effects in muscle mass and acceleration performance and large improvements in 1RM bent over row strength associated with strongman compared to traditional training. Small to moderate positive changes in 1RM squat and deadlift strength, horizontal jump, COD turning ability and sled push performance were associated with traditional compared to strongman training. These results suggest that strongman and traditional training approaches may elicit similar responses over short-term training periods.

This thesis provides insight into strongman implement training and its potential applications for strength and conditioning practice. The studies presented in this thesis provide the first evidence of how strength and conditioning coaches utilise strongman implements in practice and the injury epidemiology associated with strongman implement training. The biomechanical studies provide insight into the acute stresses associated with strongman implement training and the likely long-term chronic adaptations associated with these implements. The training study provides the first empirical evidence of the chronic effects of strongman resistance training on body composition, strength, power, and speed measures. Strength and conditioning coaches can use the data from this thesis as a possible source of new ideas to diversify and improve their training practices. The data can be used to help guide programming, which can be used to help maximise the transfer of training to sport performance and therefore improve training efficiency.

CHAPTER 1. PREFACE

1.1 Thesis Rationale and Significance

In recent years, the sport of strongman has recorded a surge in popularity in many countries of the world, both as a spectator sport and in terms of the number of active competitors. Advocates of strongman implement training espouse that this type of training is more functional than traditional gym based training approaches. Traditional gym based training exercises are generally performed with two feet side by side and require the load to be moved predominantly in the vertical direction (Keogh, Payne, Anderson, & Atkins, 2010c). Strongman events such as the farmers walk, tyre flip and sled pull involve vertical and horizontal movements 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 implements/events into the conditioning programmes of their athletes (Baker, 2008; Corcoran & Bird, 2009; Hedrick, 2003; Poliquin & McDermott, 2005; Zemke & Wright, 2011). However, there has been no peer-reviewed research on: a) how strongman implements are currently utilised in strength and conditioning practice; b) the possible injury potential associated with this form of training; c) the biomechanical profiles of strongman events; and, d) how effective these strongman exercises/implements are at improving performance.

To date, only two studies have investigated strongman implements in strength and conditioning practice (Baker, 2008; Winwood, Keogh, & Harris, 2011). While these studies give valuable insight into some issues affecting strongman training with large groups of athletes, and the training practices of strongman competitors (respectively), there is no empirical evidence for how strength and conditioning coaches incorporate strongman implements into the training of their athletes. Research is needed to determine how strongman implements are currently used in practice and why these implements are used over traditional, evidence-based methods.

Injury epidemiology has been examined in power-lifting (Brown & Kimball, 1983; Goertzen, Schoppe, Lange, & Schulitz, 1989; Haykowsky, Warburton, & Quinney, 1999; Keogh, Hume, & Pearson, 2006; Raske & Norlin, 2002), weightlifting (Calhoon & Fry, 1999; Konig & Biener, 1990; Kulund, Dewey, Brubaker, & Roberts, 1978; Raske & Norlin, 2002; Ren, Rong, Shi, Wang, & Xi, 2000) and bodybuilding (Eberhardt, Dzbanski, Fabirkiewicz, Iwanski, & Ronge, 2007; Goertzen, et al., 1989). While these studies provide critical information about injury prevalence and rates and some insight into causation, no such study has been undertaken with strongmen. The knowledge of injuries associated with strongman implement training could help guide programming into how and what type of strongman type implements athletes and strength and conditioning coaches could safely incorporate into their programmes, particularly in relation to the progression of exercise prescription.

Recently, researchers have investigated the kinematics of two strongman events, namely the tyre flip and the heavy sprint-style sled pull in order to gain insight into the kinematic determinants of these tasks (Keogh, Newlands, Blewett, Payne, & Chun-Er, 2010b; Keogh, et al., 2010c). However, the only kinetic investigations of strongman events focused on the lower back and hip abductor loading inherent to these exercises (McGill, et al., 2009). A greater understanding of the kinematics and kinetics associated with strongman events like the farmers walk, tyre flip and heavy sled pull would provide data into the possible acute stresses that strongman training imposes on the system and give some indication into the potential chronic adaptations to such training.

The physiological adaptations to traditional resistance training are widely documented (Crewther, Cronin, & Keogh, 2005; Folland & Williams, 2007; Fry, 2004; Gabriel, Kamen, & Frost, 2006; Kraemer, Noble, Clark, & Culver, 1987; Kraemer & Ratamess, 2005; Sale, 1988). While strongman implement training is becoming more widely used in the conditioning programmes of many athletes (Baker, 2008; Hedrick, 2003), no scientific evidence exists as to the morphological and mechanical adaptations associated with strongman training. It could therefore be argued that practitioners advocating the use of strongman exercises in athletic conditioning may be engaging in promotion without evidence. Researchers have suggested that the more similar a training exercise is to actual physical performance, the greater the probabilities of positive transfer (Stone, Stone, & Sands, 2007). Strongman exercises such as the farmers walk, tyre flip and heavy sled pull are deemed more functional and sports specific than traditional gym based exercises such as the deadlift, power clean and squat, and may have greater strength transferability than traditional gym based exercises. However, no peer-reviewed evidence exists to support this claim. An evidence base could help guide programming and give support to the use of strongman implements in strength and conditioning programmes.

Currently, there appears to be a paucity of scientific study into the use of strongman implements in strength and conditioning practice. 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. This thesis will provide original academic research into the use of strongman implement training and contribute to the field of strength and conditioning by providing a broad experimental application to this body of knowledge.

1.2 Research Question and Aims

This thesis sought to answer the overarching research question "what are the applications of strongman implements in strength and conditioning practice?" Six separate but related studies were used to investigate the possible risks and benefits of strongman implement training in strength and conditioning practice. The specific aims of these six studies were to:

1) To gain some insight into how strongman implements are currently used in strength and conditioning practice.
2) To gain some insight into the injury epidemiology associated with strongman athletes.
3) To compare the kinematics and kinetic profile of the farmers walk with the traditional exercise the deadlift and unloaded walk.
4) To compare the kinematics and kinetic profile of the heavy sprint style sled pull with the traditional exercise the back squat.
5) To compare the kinematics and kinetic profile of the log lift with the traditional exercise the clean and jerk.
6) To compare the effectiveness of strongman implement training versus traditional training in improving aspects of muscular function and performance.

1.3 Research Design

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

1) To determine how strongman implements are currently used in strength and conditioning practice an exploratory descriptive study was employed. Strength and conditioning coaches completed a survey adapted from surveys used with rowers and strongman competitors (Gee, Olsen, Berger, Golby, & Thompson, 2011; Winwood, et al., 2011).
2) To determine the injury epidemiology of strongman athletes an exploratory descriptive study was employed. Strongman competitors completed a survey adapted from that used with power-lifters (Keogh, et al., 2006).
3) A cross-sectional descriptive design was used to compare the kinematics and kinetic profiles of the farmers walk and deadlift
4) A cross-sectional descriptive design was used to compare the kinematics and kinetic profiles of the heavy sprint-style sled pull and back squat.
5) A cross-sectional descriptive design was used to compare the kinematics and kinetic profiles of the log lift and clean and jerk.
6) A randomised comparative trial was used to determine the chronic effects of strongman training versus traditional training on aspects of muscular function and performance.

1.4 Originality of the Thesis

Currently, very little evidence exists in the scientific literature on the sport of strongman:

1) No study has determined how strongman implements are currently used by strength and conditioning coaches.
2) No study has investigated the injury epidemiology associated with strongman athletes.
3) Research into the kinematics and kinetic profiles of strongman events is very limited.
4) No study has investigated the chronic effects of strongman implement training on aspects of muscular function and performance.

1.5 Thesis Organisation

This thesis consists of nine chapters. Chapter two is a review of the literature that explores the current literature on strongman. Due to the relative lack of peer-reviewed research, it reviews literature on the sport from a range of sources including books, review articles and scientific studies. Chapters three and four are exploratory studies, chapters five, six and seven are cross sectional descriptive studies and chapter eight is a randomised experimental study. The studies are presented in the format of the journal for which they were written, with the exception that each study is preceded by an explanatory prelude rather than an abstract. 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 scientific studies, ethics approval, participant information sheets, questionnaires, informed consent forms, and additional data. The literature review was written to summarise the research pertinent to each of the six scientific papers presented in this thesis. The review clearly demonstrates the deficiencies in our current knowledge about strongman implementation in strength and conditioning practice and establishes the significance of the scientific studies presented in chapters' three to eight. 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. STRONGMAN IMPLEMENT TRAINING: A REVIEW

"It is in the muscles of the trunk rather than the limbs that real strength lies…" (Gardiner, 2002, p. 55)

2.0 Prelude

Strongman is a sport similar to weightlifting, bodybuilding and power-lifting in which weight training is the primary form of training. Since the sports inception in 1977, the sport of strongman has grown in popularity in many countries, both as a spectator sport and in terms of the number of active competitors. Strongman competitions are hosted at local, regional and national levels and competitors compete in divisions based on age, body mass, gender and experience. Elite strongman 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 log clean and press, tyre flipping, and the farmers walk. Some strongman events are similar to that of weightlifting and power-lifting competitions where the athlete attempts to lift the heaviest load possible for one repetition. Other events such as the tyre flip (Figure 2.1) are timed with the winner being the fastest athlete to complete the event.

Figure 0.1: 2012 New Zealand North Shore regional strongman competition.

While the sport of strongman is relatively new, its origins lie deeply in our past. Man's fascination with the mystic of strength has been dominant throughout our history. Thus, feats of strength and the uses of training implements in the pursuit of strength have been recorded for thousands of years. Ancient poems from Homeric poets celebrated warriors who could hurl rocks that "two men such as live now could scarcely lift" (Gardiner, 2002). Such stories have been confirmed by discoveries in Greece from the sixth century. A block of red sandstone weighing 315 lb found in Olympia bore the inscription stating that one Bybon (son of Pholos), threw it over his head with one hand (Gardiner, 2002). A larger block, weighing 480 kg, was found at Santorin, bearing the inscription 'Eumastas, the son of Critobulus, lifted me off the ground' (Gardiner, 2002). Those stones indicate that physical strength and strong men were valued in Greece about 2,600 years ago.

Other evidence, in the forms of historical paintings and drawings, show the use of training implements to enhance physical performance. Wall paintings on the tombs of Beni Hasaan in Egypt depict figures wrestling and swinging weights. Similar forms of physical training have also been revealed in an archaeological examination of ruins in ancient India (Brzycki, 2000). One of the earliest drawings (believed to be drawn over forty-five hundred years ago) is in a funerary chapel in Egypt which shows three men exercising by lifting heavy bags over their heads (Gardiner, 2002). While ancient civilisations such as the Chinese, Indians and Egyptians practised resistance exercise with a variety of implements, credit has traditionally been given to the Greeks for producing the forerunners of our modern weight training equipment (Todd, 1966).

Athletics, art and religion were extremely important to the Greeks. Athletes competed at athletic festivals to win favour with the Gods, to oust their competition and to have the honour of being crowned with the 'olive wreath' (Gardiner, 2002). The most famous of these festivals started in Olympia in 776 B.C., which heralded our modern Olympics. The types of events held at the athletic festivals were chariot races, wrestling and hurling the *diskos*. The *diskos* was a word that meant a 'thing for throwing' which could have been any object near at hand such as a stone, lump of metal or tree trunk (Gardiner, 2002).

One of the famous strong men of ancient Greece was Milo of Crotona, a sixth century B.C. wrestler celebrated for his strength as well as his invincibility. Milo is known as the father of progressive resistance exercise, as Milo is best remembered today as the man who decided to strengthen himself for his sport by lifting and carrying across his back a calf, until it was a fully grown bull (Atha, 1981). This unorthodox training method may have worked well for Milo in the wrestling arena as he was wreathed six times at Olympia as well as many times in the Pythian and Nemean Games (Gardiner, 2002).

In contrast to the Greeks, the Romans, considered training for warfare much more appropriate than training for sports. Roman soldiers used heavy training implements (i.e. heavier-than normal armour and over-weighted swords) as part of their battle training drills (Gardiner, 2002). According to Pliny the Elder (A. D. 23-79), the professional strength athlete, Athanatus, walked around in the arena while wearing armour that weighed about 1,000 lb (Gardiner, 2002). Some of the most direct transfer of strengthening exercises during the Roman period can be seen in the way the gladiators were prepared for the arena (Gardiner, 2002).

While training with weights was a staple exercise among Roman athletes, the practice died out after the fall of the Roman Empire but was revived in the 16th century. In 1531, Sir Thomas Elyot advised exercise (based on Galen's recommendation of resistance exercise) "labouring with poises [weights] made of lead or other metal called in Latin *alteres* [dumbbells] " along with "lifting and throwing the heavy stone or bar" (Lemberg, 1962). Soon after in 1544 Joachim Camerarius recommended exercise in school, including "climbing a rope, lifting weights, and matching strength with an opponent in various ways" (Leonard, 1923). In time, such ideas crossed the Atlantic to America (Todd & Hoberman, 2007).

While the previous paragraphs have demonstrated the use of many types of training implements across a range of cultures throughout our history, it may be the Scottish, which holds the greatest influence on the modern sport of strongman. The Highland games come from very ancient origins. The earliest known Celtic celebrations of sporting and cultural endeavour are the Tailteann games which ran from 1829 B.C to 1180 A.D. These sporting festivals preceded the Olympics in Greece and came to Scotland by the way of Ireland (Webster, 2011). The Scottish Highland Games are the modern continuation of this ancient Celtic tradition and have now grown to become one of Scotland's largest sports, which are popular throughout the world. Today various countries bid years in advance to hold the World Highland Games Championships which include some of the world's strongest men (Webster, 2011).

While many of the events in the Highland games are unique, similarities exist between many of the events in the sport of strongman. The most notable of these is the use of heavy stones. Stones of strength (or manhood stones) were used by Scottish youths to prove they had reached manhood by lifting the stone onto a wall or a barrel at waist height (Webster, 2011). Similar tests of strength were used to select elite Scottish warriors (Webster, 2011). Iceland also had stone lifting tests for their warriors. The Vikings used heavy stones to determine the seating positions of the men in longboats, with those that lifted the heaviest stones gaining position in the middle of the boat (Webster, 2011). It could be therefore be surmised that like modern strongman athletes these ancient cultures trained with stones of various weights and sizes to accomplish their goals.

The uses of heavy stones are commonly observed in many strongman competitions throughout the world (Figure 2.2). Other Highland games events using stones were 'putting the stone' and 'stone loading' races. Similar stone loading events are seen in the sport of strongman, such as the Cradle of iron event. Loading races using kegs and sandbags in the sport of strongman are also common.

Figure 0.2: Strongman athlete lifting an atlas stone

Figure 0.3: Steel logs used for the farmers walk

The caber toss is one of the most distinctive Scottish sports. The wooden cabers were approximately 16-18 feet and were thick at the top end and thin at the bottom. The lifter had to run and heave it, to toss it onto its heavy end, and overturn it directly aligned with the lifter. Similar events are appearing in strongman competitions i.e. Fingal Fingers; however, the logs are much heavier and pivot on a fulcrum at the ground. Wooden and steel logs are also used in other strongman events such as the farmers walk (Figure 2.3) and log lift (Figure 2.4). Similarities also exist with other Highland games events such as the ‘sheaf toss’ and ‘56 lb weight for height’ (Figure 2.5). The ‘keg toss’ is an event in which strongman competitors must throw a weighted keg over a bar of a certain height.

Figure 0.4: Steel log used for log lift

Figure 0.5: Weight for height event with 56 lb load

Our history demonstrates that some of the implements used in the sport of strongman, have been utilised by strong men for thousands of years. It is not surprising then that these implements that were deemed to be effective for preparing men for battle (when their lives depended on their physical strength) are now becoming popular in strength and conditioning practice. The advocates of strongman implement training propose that these exercises are more functional than traditional training approaches and therefore better replicate sporting movements. However, due to a scarcity of research no evidence exists in the scientific literature to support this claim. The following literature review explores the scientific literature on the use of strongman implements in strength and conditioning practice. The review addresses the potential shortcomings of strongman implementation in practice and provides justification for the studies represented in this thesis.

2.1 Introduction

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. Each strongman competition is somewhat 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 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, strength and conditioning coaches are beginning to incorporate strongman exercises into the conditioning programmes of their athletes (Baker, 2008; Bennett, 2008; Bullock & Aipa, 2010; Corcoran & Bird, 2009; Hedrick, 2002, 2003; Zemke & Wright, 2011).

Generally, most traditional gym based resistance training exercises are vertical in nature and performed with the two feet side by side. In contrast, human gait consists 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, 1999), 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. It has been suggested that athletes could further improve their competition performance, if the design of their resistance training programme focuses on horizontal movement-specific exercises as well as traditional vertical exercises (Randell, Cronin, Keogh, & Gill, 2010). Such a view may be based on the principle of specificity. Stone and colleagues (2007) have suggested that the more similar a training exercise is to actual physical performance, the greater the probabilities of transfer. Advocates of strongman training suggest it is more specific than other forms of strength training and may help ‘bridge’ the gap between gymnasium-based strength training and functional performance.

Mills and colleagues (2005) defined functional movement as the ability to produce and maintain balance between mobility and stability along the kinetic chain while performing fundamental patterns with accuracy and efficiency. The term ‘functional training’ can refer to interventions that help correct movement patterns, balance and stability to improve functional independence. For the purpose of this thesis functional training is defined as “the execution of movements directly related to patterns required for a given sport, with the intent of improving athletic performance”. Strongman events represent functional movements and challenge the whole musculoskeletal system in terms of strength, stability, and physiological demands (McGill, et al., 2009). The inclusion of strongman exercises in training programmes such as the tyre flip, truck pull, farmers walk and yoke walk along with more common gymnasium-based lifts such as the power clean, deadlift and squat may therefore further improve the performance of many athletic groups. However no training studies have been conducted to support this hypothesis.

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 elicit different strength and power characteristics (McBride, Triplett-McBride, Davie, & Newton, 1999). Recent articles published on the sport of strongman have suggested how to incorporate strongman exercises in strength and conditioning programmes (Bennett, 2008; Hedrick, 2003; Waller, Piper, & Townsend, 2003; Zemke & Wright, 2011), which have provided valuable insight into the possible use in strength and conditioning practice. However, such studies have provided little scientific evidence to support the use of strongman exercises in strength and conditioning practice. The review of Zemke and colleagues (2011) overcame some of these limitations by briefly discussing the findings of some of the scientific studies, and provided some suggestions from the evidence base. Guidelines of how to incorporate strongman exercises in strength and conditioning practice are generally based on anecdotal evidence and authors’ knowledge. None of these articles have yet provided a scientific and extensive review of the research on the sport of strongman to help guide strength and conditioning practice.

To date studies have investigated the metabolic and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of strongman exercises (Berning, Adams, Climstein, & Stamford, 2007; Keogh, et al., 2010b; Keogh, et al., 2010c; McGill, et al., 2009); the issue of practicality of overload in strongman training when dealing with large groups of athletes (Baker, 2008); and more recently, research has investigated how strongman athletes train, and the relationships between strength, anthropometry and strongman competition performance (Winwood, et al., 2011; Winwood, Keogh, Harris, & Weaver, 2012).

The following review explores the proposed benefits of strongman training and examines the current scientific literature on the sport of strongman (including recent studies that were not cited by Zemke and colleagues (2011)) and makes recommendations based on current scientific evidence on how these unique training modalities could benefit the conditioning programmes of other athletes. The review addresses the potential shortcoming of practice in strength and conditioning and provides directions for future research on the sport of strongman.

2.2 Literature Search Methods

This review evaluated and interpreted the current evidence base to provide coaches, sport scientists and athletes alike, with an understanding of the rationale and application of strongman training to strength and conditioning practice. The conclusions and practical applications of this review were drawn from peer-reviewed journal publications. The databases searched were Academic Search Premier, SPORT Discus, PubMed, MEDLINE, and CINAHL. Literature searches were undertaken using several key words including 'strongman', 'strength and conditioning', 'strength training', 'training implements', 'resistance training', 'periodisation', 'tyre flip', 'log clean and press', 'truck pull', 'sled pull', 'stones', 'farmers walk', and 'athlete conditioning'. Only English language articles published in peer-reviewed journals were considered. Relevant literature was also sourced from searches of related articles and books arising from the reference list of those obtained from the database searches. The studies reviewed examined various strongman events that could be integrated into athletes' strength and conditioning programmes.

2.3 Proposed Benefits of Strongman Implement Training

In recent years, the use of strongman training modalities have become popular in strength and conditioning practice (Bennett, 2008; Corcoran & Bird, 2009; Ebben, Carroll, & Simenz, 2004; Hedrick, 2002, 2003, 2007; Zemke & Wright, 2011). Strength and conditioning coaches have proposed that strongman exercises are more functional than traditional training approaches. Strongman type exercises are total body movements which may better replicate sporting movements and place greater demand on the body's core musculature than other resistance training approaches. Kubik (1996) suggested that incredible levels of strength and muscular development can be achieved by combining common weight training exercises such as the squat and deadlift with the lifting of heavy, awkward, hard to manage objects such as beams, barrels, logs, sandbags or kegs. Such strength gains may occur through the training of type II muscle fibres (Sale, 1987) and the improved coordination of agonist, antagonist, synergists, and stabilising muscles (Rutherford & Jones, 1986; Sale, 1988). The following section covers a variety of strongman exercises that have been proposed to be beneficial in strength and conditioning practice. For further description of the implements and instructions for lifting technique, readers are referred to Waller and colleagues (2003).

A recent review by Zemke and Wright (2011) suggested that strongman implements can be used in an athletes periodised programme and may even help improve athlete attendance and adherence to training programmes. They proposed that events such as the farmers walk and log clean and press can be used in the general preparation training phase (GPT) to increase strength endurance and anaerobic energy systems endurance. Zemke and Wright (2011) also proposed that strongman implements could provide a great stimulus for hypertrophy due to the large amount of musculature used during these exercises and the potential for long time under tensions. This is supported by the recent research of Ghigiarelli, Sell, Raddock, and Taveras (2013) who found that strongman training elicits an acute endocrine response similar to hypertrophy protocols when equated for duration and exercise selection. This result gives some evidence to strength and conditioning coaches that strongman training could be included in the hypertrophy phase of a strength training programme.

Zemke and Wright (2011) suggested that strongman exercises can be used in sports specific physical training (SSPT) as they closely replicate movements in sport which is in agreement with other strength and conditioning coaches who are advocating the use of strongman implements. Hedrick (2003) espoused that using uncommon implements like water filled barrels enhances the need for stability and control, and with suitable progression may reduce injury risk and improve joint stability. Similar views have been made by McGill et al. (2009) based on their results which showed high degrees of core and hip abductor activation in many common strongman exercises. However, no training study evidence so far exists to support the use of strongman type implement training for injury prevention.

Strength and conditioning coaches have proposed that strongman training may prove more sports specific and more functional than conventional gymnasium-based training (Corcoran & Bird, 2009; Hedrick, 2003). Hedrick (2003) suggested that in many sporting situations, athletes encounter dynamic resistance (in the form of an opponent) as compared to a static resistance. Corcoran and Bird (2009) have suggested that strongman type exercises are ideal exercises (as a supplement to traditional power training approaches) for transferring previously attained strength gains into more ‘functional strength’. An example of this was the use of heavy sledgehammers in a rail chain gang drill. Corcoran and Bird (2009) proposed that this drill closely simulates the action required to pull an opposition player forcefully to the ground as required in rugby union. Currently, however no research exists to support the view that strongman type exercises transfer previously attained strength gains into more ‘functional strength’, or if strength gains through strongman training positively affect athletic performance.

The tyre flip is an exercise often seen in strongman competitions and as a conditioning exercise for a variety of athletes. Its apparent popularity may be because strength and conditioning coaches believe that the tyre flip has greater specificity to a variety of sport specific movements than can be achieved with traditional gymnasium-based resistance training. The tyre flip involves knee and hip extension, plantarflexion, shoulder flexion and elbow extension. Waller and colleagues (2003) suggested that the tyre flip replicates the same movements an American football lineman would use exploding out from a 3-point stance, however no biomechanical study has been done to add support to this view. Corcoran and Bird (2009) suggested that the tyre flip, set up in a grid to emphasise the approach “through the gate”, encouraged the desired body position (i.e. shoulders above hips) in clean out situations in rugby union.

The tyre flip is also similar to the weightlifting movements because of the explosive triple extension that occurs at the ankle, knee and hip. However, the tyre flip does not contain the double knee bend as seen in weightlifting and may not elicit the same adaptations as seen in weightlifting, such as the development of the stretch shortening cycle. The tyre flip may however have some advantages over exercises such as the power clean, as its been suggested that the tyre flip is less technically demanding than the power clean which allows athletes to place greater emphasis on speed of movement (Hedrick, 2002). Loading limitations may however exist with the tyre flip. In weightlifting, an athletes' ability to personalise the load is limitless whereas there are only a limited number of tyre weights available. Studies are needed to compare the biomechanics of these activities and training adaptations from each.

Some practical recommendations have been proposed for the tyre flip. Bullock and Aipa (2010) suggested that strength and conditioning coaches should consider the dimensions of the tyre, including the height, width and weight when selecting tyres for athletes. Taller tyres (when standing upright) may be more difficult for a shorter athlete to flip, and a tyre with a narrow width may be more difficult for a taller athlete because of limb length and depth requirements (Bullock & Aipa, 2010). Other factors that can contribute to tyre flipping difficulty are the density of the rubber, tyre tread and hand clearance (Havelka, 2004). In addition, surface type could affect tyre flipping through the various frictional coefficients. For example, a greater coefficient of friction may help with the lift of the tyre off the ground but reduce the distance the tyre travels in the push. Pictorial representations of the tyre flip are presented in Figures 2.7 and 2.8.

The use of strongman exercises such as the 'truck pull' and 'heavy sled pull' (Figure 2.6), have been proposed to increase sprinting performance (Keogh, 2010a). The rationale behind this is that increases in the two direct determinants of sprinting speed (stride rate and stride length) may occur via the production of greater propulsive horizontal (anterior-posterior) forces and impulses (Hunter, Marshall, & McNair, 2004). Heavy sled pulls may however have some advantages over the truck pull in strength and conditioning practice. Heavy sled pulls mimic the same actions as the truck pull and allow for easy loading changes. They can be done on tracks and indoors which may be inaccessible for cars and trucks of different sizes. Keogh (2010a) suggested that for relatively strong male athletes (i.e. athletes' that can squat 1.5x body weight) weighing 85-120 kg, that a load of 150-220 kg might be appropriate for sprint-style sled pulls of 25 m performed on astro-turf or grass surfaces, with this likely taking such athletes 10-20 seconds to complete. Keogh (2010a) also suggested that such load may have to change depending on the surface type; surfaces with a greater coefficient of friction such as rubber sprint tracks may require less total weight to obtain the same training effect.

The use of 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). Baker and Newton (2008) suggested that the ability to generate greater sprint momentum over short sprints (typically 10 m) is of considerable importance in rugby league to aid in tackling opposing players when in defence and in helping to break tackles when in attack. Interestingly, the use of sled pulls has also been proposed to improve performance capabilities in ice hockey (Pollit, 2003). Pollit (2003) proposed that dragging the sled is a closed chain multijoint exercise that allows the posterior muscle chain to be worked in a functional skating motion, as opposed to strength training in which muscles are trained with less functional specificity. However, research is needed to validate such a view.

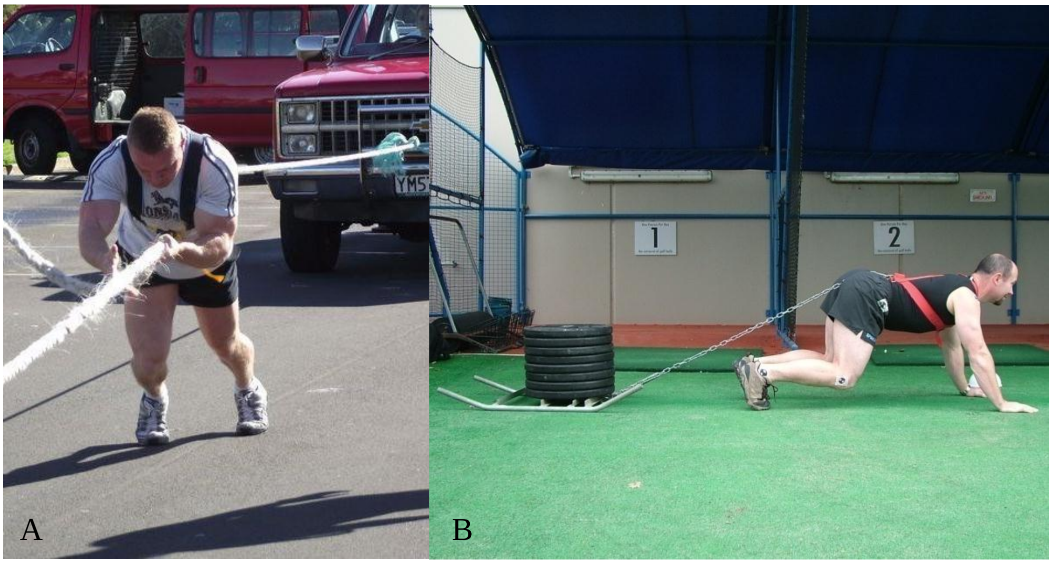

Figure 0.6: Illustration of the strongman pulling events. A = truck pull; B = the heavy sprint-style sled pull (Modified with permission from Keogh, et al., (2010b))

The farmers walk is arguably one of the most functional strongman exercises involving holding heavy objects in each hand and walking as quickly as possible for a set distance or time. Pictorial representations of the farmers walk are presented in Figures 2.3 and 2.7. This exercise has some similarities to the truck pull and heavy sled pull in that it would appear to require the production of high horizontal as well as vertical unilateral forces. Hence, the farmers walk may have some transferability to sports that involve sprinting type movements. It has been proposed that the farmers walk helps to develop total body stamina, core strength and stability, anaerobic endurance and grip strength (Waller, et al., 2003). Studies have demonstrated that grip strength is an indicator of performance in many sports such as weightlifting (Fry, et al., 2006), cricket (Koley & Yadav, 2009) and baseball (Hoffman, Vazquez, Pichardo, & Tenenbaum, 2009). McGill (2010) proposed that asymmetric carries such as unilateral farmers walk (referred to as the suitcase carry) would assist many athletes in training the torso brace and strength to support the hips, pelvis and spine.

2.3 Problematic Issues with Strongman Implement Training

While many strength and conditioning coaches are advocating the use of strongman implement use in strength and conditioning practice, little scientific evidence exists to support their use. To date only one study has investigated the use of strongman implements in strength and conditioning practice. Baker (2008) investigated the problematic issue in how to adequately load a variety of athletes (of different heights, body weights, strength levels or upbringings i.e. those with a manual labour background versus those who do not) within a team situation when using strongman training in an anaerobic conditioning session. Baker (2008) attempted to develop a pre-season mixed training session of strongman exercises such as tyre flipping, log carrying and water filled conduit carrying coupled with some running conditioning, to replicate the nature of rugby league. The training session was designed so that the seven elite rugby league player's heart rates averaged between 165-175 bpm, in order to replicate the average heart rate (HR) conditions in a game. While four of the players average HR were within the specified range, the average HR for the other three players were between 139 and 156 bpm. These three players had the highest squat scores (190, 195 and 220 kg) and two of these three players had the highest body mass (107 and 112 kg). Interestingly, the results demonstrated an inverse relationship between squat strength and average HR in the strongman training session. This may be due to the tolerance of physiological stress placed on the body's systems. The stronger athletes would have less physiological stress placed on them compared to their weaker counterparts at a given load. Recently, Winwood and Colleagues (2012) demonstrated that squat strength is highly correlated to strongman competition performance ($r = 0.85$) for a competition involving the tyre flip, log clean and press, truck pull and farmers walk. 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. The results from this study demonstrate that strongman implements may have to be modified to allow for easy loading changes so that athletes of varying levels of strength can achieve the same relative loading. An example of this is given by Hedrick (2002), who suggested that implements like the tyre flip can be modified so that athletes can attach weights to the centre of the tyre. Such methods will allow strength and conditioning coaches and athletes to vary resistance based on individual strength levels. However, strength and conditioners may still be limited in the number of tyres weights and sizes available. Baker (2008) suggested that acquiring and storing strongman objects such as tractor tyres, logs, and kegs can also be big issues for strength and conditioning coaches.

2.4 Metabolic Responses of Strongman Implement 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 and pulled a 1,960 kg motor vehicle for 400 m. The athletes had a minimum of five years resistance training experience with training sessions involving power-lifting and weightlifting movements. The mean time to complete the push was 6:00 minutes and pull was 8:02 minutes, but there were no statistical differences in oxygen uptake (VO_2), heart rate, and blood lactate (BLa) between the pushing and pulling conditions. Interestingly, VO_2 and HR peaked within the first 100 m (65% and 96% (respectively) of treadmill VO_2max values) and there were no significant increases in VO_2 or HR thereafter for either the push or pull. Blood lactate concentration from the push and pull, as measured immediately after completion of the 400 m course, reached an average concentration of 15.6 $mmol.L^{-1}$, representing a value 131% of the maximal treadmill running test.

The subjects were ‘exhausted’ after the event, which may explain the acute 10 cm decrement suffered in vertical jump height immediately after each of these tasks, amounting to a reduction of ~17% of baseline maximum jump height. Studies have demonstrated that the greater the force exerted by a muscle or motor unit, during a given task, the more the muscle will fatigue (Enoka & Stuart, 1992; Hunter & Enoka, 2001), and subjects with higher anaerobic power reserves record larger power decrements (Hamilton, Nevill, Brooks, & Williams, 1991; Mendez-Villanueva, Hamer, & Bishop, 2008 ; Wadley & Le Rossignol, 1998). Strongman events such as the truck pull which are associated with an increased participation of anaerobic metabolism, may result in a greater accumulation of metabolites (i.e. lactate, H+) and decrements in energy stores (i.e. PCr) (Gaitanos, Williams, Boobis, & Brooks, 1993; Hirvonen, Rehunen, Rusko, & Harkonen, 1987). Studies using weightlifters, bodybuilders and power-lifters who performed acute lifting protocols, have shown blood lactate values were routinely >10 $mmol^{-1}$ (Fry, et al., 1994a; Fry, et al., 1994b; Hakkinen & Pakarinen, 1993; Kraemer, et al., 1992; Kraemer, et al., 1987; Warren, et al., 1992). The metabolic acidosis as a result of the truck pull may cause important adaptations in lactate production and clearance levels and tolerance levels (Brooks, Fahey, & Baldwin, 2005; Juel, et al., 2004). Such adaptations may be beneficial for athletes in sports such as wrestling (Karnincic, Tocilj, Uljevic, & Erceg, 2009), martial arts (Artioli, et al., 2009), boxing (Ghosh, 2010; Smith, 2006) and rowing (Messonnier, Freund, Bourdin, Belli, & Lacour, 1997). Messonnier and colleagues (1997) found that the ability to row at high relative work rates was associated with improved lactate exchange and removal abilities. While the truck-pull may be possible option for anaerobic training, strength and conditioning coaches must do so with caution. Truck pull training could have negative long-term adaptations if performed too frequently (Hakkinen, 1993; Jansenn, 2001). Winwood and colleagues (2011) found that only 48.5% of strongman competitors included the truck pull in their strongman training and 'less than once a week' was the most common reported training practice (69.1%). Such a result suggests that strongman competitors may be aware of the high physiological stress this event places on the body's systems.

A potential limitation of the study of Berning and colleagues (2007) is that the distance of 400 m is substantially more than that seen in strongman training and competition. Recent research demonstrated that 30 m was the most common reported training practice (39.5%) performed per set for truck pull training among strongman competitors (Winwood, et al., 2011). However, the study by Berning et al. (2007) demonstrates that peak exertion was achieved relatively quickly with peak responses (VO_2 and HR), being achieved between 50 and 100 m (a distance that would have most likely been completed between 50-90 seconds). While no studies have yet investigated the physiological adaptations to strongman training, recent research demonstrated that strongmen have a lower relative VO_2 max than the marathoners and sedentary controls, and the relative cardiac size in strongmen was smaller than in endurance runners (Venckunas, et al., 2011). Venckunas and colleagues (2011) revealed that strongmen had impaired myocardial relaxation (lusitropic function), and their blood lipid profile was not different from that of sedentary controls, and was less favourable than in endurance athletes. The differences between strongmen and marathon runners may be due to the different types of training, and could also be related to diet (i.e. animal fat and protein), body composition or the use of anabolic steroids.

Keogh and colleagues (2010b) 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 with a three minute rest between sets. Physiological stress was examined using heart rate (HR) and finger-prick blood lactate (BLa) response. Findings from this study showed that the mean HR and BLa values at the conclusion of the second set were 179 beats per minute (bpm) and 10.4 $mmol.L^{-1}$ respectively. These findings of Keogh and colleagues (2010b) therefore appear somewhat comparable to the car push/pull results of Berning et al. (2007) suggesting that due to the high physiological demands of strongman exercises, that they could prove useful in improving anaerobic conditioning (through adaptations in lactate production and clearance mechanisms and tolerance levels (Brooks, et al., 2005; Jansenn, 2001; Juel, et al., 2004)) and for increasing energy expenditure.

2.5 Hormonal Responses of Strongman Implement Training

Hormones can affect almost every physiological function in the body and the close association of hormones to the nervous system makes the neuroendocrine system potentially one of the most important physiological systems related to resistance training (Fleck & Kraemer, 2004). It has been suggested that by properly manipulating strength training programmes it is possible to stimulate hormonal increases that will lead to superior physiological adaptations (Brzycki, 2000). Heavy resistance exercise has been shown to induce acute hormonal responses, which are dependent on the type of exercise protocol (Hakkinen & Pakarinen, 1993; Smilios, Pilianidis, Karamouzis, & Tokmakidis, 2003). A variety of resistance exercise protocols result in an acute increase in serum testosterone (Schwab, Johnson, Housh, Kinder, & Weir, 1993) and cortisol (Hakkinen & Pakarinen, 1993) causing an alteration of the anabolic/catabolic status. This alteration affects the regulation of skeletal muscle growth through changes in either protein synthesis or degradation (Bird & Tarpenning, 2004). Testosterone stimulates muscle protein synthesis and promotes muscle mass growth whereas cortisol has a catabolic effect on myofibrillar proteins and suppresses protein synthesis (Smilios, et al., 2003).

While numerous studies have investigated the acute and chronic hormonal responses to resistance training (Hakkinen & Pakarinen, 1993; Hakkinen, Pakarinen, Alen, Kauhanen, & Komi, 1988; Hartman, Brandon, Bemben, Lon Kilgore, & Bemben, 2007; McCall, Byrnes, Fleck, Dickinson, & Kraemer, 1999; Smilios, et al., 2003) only one recent study has investigated the effects of strongman training on hormonal responses (Ghigiarelli, et al., 2013). Sixteen resistance trained males completed three resistance training protocols (two strongman training protocols and an established hypertrophy protocol) over a 3 week period with a one week recovery period between each session. The strongman only protocol (ST) comprised of the tyre flip, chain drag, farmers walk, keg carry, atlas stone and the hypertrophy protocol (H) comprised of the back squat, leg press, bench press and seated row. The mixed strongman/hypertrophy (XST) session consisted of performing exercises from both the ST and H protocols (tyre flip, back squat, chain drag, bench press and stone lift). In the H and XST protocols the subjects performed 3 sets of 10RM to failure with a load of 75% predicted 1RM whereas in the ST protocol subjects were required to perform 3 sets to muscle failure. Subjects rested for 2 minutes between sets and exercises in all protocols. Saliva samples were collected pre-exercise (PRE), immediately post exercise (PST) and 30-minutes post exercise (30PST). Significant differences in testosterone levels were apparent between PRE and PST within each group $p \leq 0.05$, with no significant differences between groups. Testosterone levels spiked 136% (225.23 ± 148.01 $pg \cdot ml^{-1}$) for the H group, 74% (132.04 ± 98.09 $pg \cdot ml^{-1}$) for the ST group and 54% (122.10 ± 140.67 $pg \cdot ml^{-1}$) for the XST group. Interestingly, a significant difference ($p \leq 0.05$) for testosterone level occurred over time (PST to 30PST) only for the H group. A limitation to this study was the inability to control and measure the volume of load over a given time period. Therefore, the magnitude of neuromuscular stress imposed on the subjects may have differed across the resistance training protocols making comparison somewhat difficult. The study of Ghigiarelli and colleagues (2013) did however demonstrate that strongman training elicits acute endocrine responses which may be beneficial for improving muscular hypertrophy. Biomechanical studies (i.e.

kinematic and kinetic analysis) on strongman implements are needed as the data could be used to better determine loading parameters in subsequent training studies.

2.6 Biomechanical Demands and Determinants

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 quantified and compared across several strongman exercises (farmers walk, tyre flip, yoke walk, Atlas stone lift, suitcase carry - unilateral farmers walk, keg walk, and log lift) using a sample of three experienced strongman, one of whom was world-class. Pictorial representations of these strongman events are presented in Figure 2.7. 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 electromyography (EMG)). However, differences existed between the lifts in regards to the types of stress and muscle activation (Table 2.1). The yoke walk (YW) and stone lift (SL) produced the highest and lowest spinal joint compression loads, respectively. The keg walk (right shoulder) (KWRS) and tyre flip (TF) 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 (YW) and the left hand suitcase carry (LHSC).

The very high spinal compression loads found in the yoke walk was mainly attributed to the bracing action of the torso musculature to support the yoke load and to offset the deficiencies in hip abduction (as will be discussed later in this paragraph). An interesting finding in the study of McGill et al. (2009) was that the Atlas stone lift generated the lowest compression of the three lifts. This was because strongmen curved their torsos over the stone, getting its centre of mass closer to their lower backs. This event produced the greatest spine flexion angle as strongmen rolled the stone up the thighs onto the belly, before the extension heave onto the platform. Muscle activation levels revealed that the greatest gluteal activity (i.e. gluteus maximus and gluteus medius) occurred during the stone lift, as did the the quadriceps, the upper erector spinae and many of the abdominal muscles. In contrast, the tyre flip produced the highest activation levels in the latissimus dorsi, the lower lumbar erector spinae and the hamstrings. The walking events (i.e. farmers walk, yoke walk, left and right hand suitcase carry) demonstrated that greater activation of the abdominals (rectus abdominis, internal and external obliques) occurred during the walking rather than lift phase. However, different muscle activation levels occurred in the different phases of each event. For example, in the farmers walk the abdominal muscles were more apt to peak during the walk, whereas the lower erector spinae peaked during the lift. An interesting finding in the study of McGill et al. (2009) was that in order to generate spine and pelvis stability with torso stiffness in the carrying events, strongmen braced the torso and lifted the pelvis with lateral torso muscle (i.e. the obliques and quadrates lumborum). This was done as the abduction hip torque needed to lift the pelvis exceeded the abduction strength measured in the strongmen.

Table 0.1: Average external moment about the lumbar spine, muscular and joint compression and anterior/posterior (A/P) shear, and average masses of loads lifted in each hand (Modified with permission from McGill, et al., (2009)).

			Muscular		Joint		Mass of load lifted (kg)	
		L4/L5 moment	Compression	A/P Shear	Compression	A/P Shear	Right hand	Left hand
YW	Average	104	8020	-1894	12043	-1341	91	91
	SD	47	2631	149	2500	206	12	12
SL	Average	183	5690	-1507	5659	-635	27	27
	SD	177	3904	1548	5752	1635	24	24
KWRS	Average	431	6909	-2737	6591	-1249	100	100
	SD	70	462	106	434	55	0	0
TF	Average	792	7061	-2056	7921	-138	155	155
	SD	58	1562	243	1592	331	0	0
LHSC	Average	61	5492	-1598	6890	-1520		38
	SD	37	1242	363	1804	535		9

Key: Compression for the muscles alone is listed separately to reveal that muscle forces are the primary source of spine compression. Values for the LHSC, YW, and KWRS were collected during walking, and values for the TF, and SL were collected during the lifting phase. LHSC = left-hand suitcase carry; YW= yoke walk; TF = tyre flip; SL = stone lift; KWRS = keg walk–right shoulder.

Figure 0.7: Illustration of various strongman events. A = farmer's walk; B = left hand suitcase carry; C = yoke walk; D = tyre flip; E = log lift; F = stone lift G = right-shoulder keg walk (Reprinted with permission from McGill, et al., (2009))

The differences in the joint kinetics and muscle activation of these strongman events therefore suggest that while all of these events impose core stability demands on these athletes, the core stability demands of these events are somewhat task-specific. Strongman exercises such as the yoke walk and suitcase carry uniquely challenge the lateral musculature (e.g. quadratus lumborum and oblique abdominal wall) (McGill, 2010; McGill, et al., 2009) 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 strongman lifting events (tyre flip, Atlas stone lift and log lift) in the study of McGill et al. (2009) involved hip extension with torso stiffness, which was accomplished with abdominal and extensor muscle bracing. Interestingly, the less accomplished strongmen in this study were found to have greater spinal load than the world class athlete as they used their back muscles rather than hip extensor torque to move the core linkage.

The between-exercise differences in the level of muscle activation found in the study of McGill et al. (2009) are similar to Anderson and colleagues (2007) who found a significant effect of both walking speed and load height on trunk posture and trunk muscle activity levels. The eleven subjects in the Anderson et al. (2007) study performed standing and walking trials with a barbell and a 14 kg bucket of potatoes carried at three different heights (knuckle height, elbow height and shoulder height). Results indicated that the walking trials in both experiments produced significantly greater trunk muscle activity than the standing trials. The rectus abdominus muscle activity increased by 132% from the standing to walking trials, while the muscle activity of the erector spinae muscles increased by 35%, 36% and 42% at the T9, T12 & L3 levels. Interestingly, the load height at the elbows produced greater rectus abdominus activity than at the knuckles, while the load at the shoulder produced the least activity. This was due as a direct result to the posture employed. Participants had a significantly greater average sagittal angle when they carried the bucket at the shoulder height, which consequently produced the highest erector spinae activity seen in the study. While no studies have compared trunk muscle activity between strongman events and traditional resistance training, one study has investigated the influence of performing squats of varied stability (Anderson & Behm, 2005). Fourteen male subjects performed Smith machine squats, free weight squats and free weight squats standing on balance discs, with a load of 60% body mass. Results demonstrated that the trunk muscles (upper lumbar erector spinae, lumbo-sacral erector spinae and abdominal stabilisers) were more active during the unstable squat, followed by the free squat and Smith machine squat, respectively. Researchers have suggested that training under unstable conditions with the same absolute load provides a greater stress to the overall musculature (Gantchev & Dimitrova, 1996; Ivanenko, Levik, Taslis, & Gurfinkel, 1997; Wester, Jespersen, Nielson, & Neumann, 1996). However, muscle activation of the prime movers can decrease if the degree of instability is too severe (Behm, Anderson, & Curnew, 2002). Strongman events such as the farmers walk that add an element of instability but are performed on a flat surface may help to increase the muscle activity of the trunk stabilisers, postural muscles and the prime movers.

While the loads used in the studies of Anderson et al. (2007; 2005) were light, the studies of Anderson et al. (2007; 2005) and McGill et al. (2009) give some evidence into how strongman events (or modifications of these) could be used in an exercise progression that further challenges the core musculature. A squat progression could be used to gain some general core strength and the athlete could then perform carrying exercises, starting with the farmers walk or suitcase carry, then progressing to a keg or zercher carry (load held in the crook of the elbows) and finally the yoke walk.

The stability of the lumbopelvic region is crucial to provide a foundation for movement of the upper and lower extremities found in most sporting activities (Panjabi, 1992). Dynamic core stability training should therefore be specific because the relative contributions of each muscle continually changes throughout a task to meet postural adjustments or the external loads imposed on the body (McGill, Drenier, Kavcic, & Cholewicki, 2003). Keogh, Aickin, & Oldham (2010a) suggested that 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. The study of McGill et al. (2009) demonstrated that strongman events create challenges to different parts of the body in terms of load and athleticism, and they suggested that loaded carrying exercises such as the farmers walk and yoke walk could enhance traditional lifting-based strength programmes. The high lumbar loads experienced during strongman training, could allow great improvements in core stability; however, they could also lead to injury especially if improperly progressed over time and if performed by athletes with insufficient training experience. Therefore, the integration of strongman events into a programme should follow the same guidelines as with any other programme (Waller, et al., 2003). Strength and conditioning coaches need to address the athlete's movement competency to help guide programming and to avoid the athlete developing potentially injurious movement patterns (Kritz, Cronin, & Hume, 2009). Needs analysis will help determine the physiological needs of the sport and what movement patterns need to be trained. Such an analysis may help determine what strongman events could be incorporated into the athlete's periodised programme and how these events can be progressed over time.

The other two biomechanical studies conducted to date have sought to characterise the kinematics of the tyre flip and heavy, sprint-style sled pull and to gain some insight into the kinematic determinants of performance in these events (Keogh, et al., 2010b; Keogh, et al., 2010c). Keogh and colleagues (2010c) performed a temporal analysis of the tyre flip using five resistance trained subjects experienced in the tyre flip. Each subject performed two sets of six tyre flips with a 232 kg tyre with three minutes of rest between sets. The duration of each tyre flip and that of the first pull, second pull, transition, and push phases were recorded. A pictorial of the four phases of the tyre flip is presented in Figure 2.8.

Results of independent T-tests showed that the two faster subjects (0.38 ± 0.17 seconds) had significantly shorter second pull durations (i.e. the phase where the tyre moved from just above the knee to the hands-off position prior to the push) than the three slower subjects (1.49 ± 0.92 seconds). Paired T-tests also showed that the duration of the second pull for each subjects' fastest three repetitions (0.55 ± 0.35 seconds) were significantly less than their three slowest repetitions (1.69 ± 1.35 seconds). The results of this study demonstrated that the duration of the second pull was the strongest determinant of tyre flip performance. Recent research using twenty-three novice strongman competitors has also demonstrated that the tyre flip had the largest correlation ($r = 0.88$) with overall strongman competition performance for a competition involving the tyre flip, log clean and press, truck pull and farmers walk (Winwood, et al., 2012). However, no study has investigated how performance in the tyre flip relates to performance in other sports such as rugby union, rugby league and American football. If a strong relationship exists, this would further support the use of the tyre flip in these types of athletes' strength and conditioning programmes.

Figure 0.8: Pictorial representation of the five positions of the tyre flip. A = start; B = tyre just above knee; C = hands leaving tyre; D = hands repositioned on tyre, E = tyre reached vertical position (Modified with permission from Keogh, et al. (2010c))

The heavy sprint-style sled pull was examined using six resistance trained subjects with some experience in performing the heavy sled pull (Keogh, et al., 2010b). The subjects were connected to the sled via a chest mounted harness and chain. The subjects started in a 4-point stance position and performed three 25 m sets of sled pulls with a load of 171.2 kg with 3 minutes of rest between sets. The majority of the 25 m heavy sled pulls took 12-18 seconds to complete with the range being 10-40 seconds. 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 angle in several phases of these sled pulls than what is considered normal for acceleration sprinting. Within- and between-subject analyses of the fastest and slowest trials revealed more significant differences in the maximum velocity phase (last 5 m) than the acceleration phase (first 5 m) of the sled pull. The fastest trials were characterised by significantly greater step lengths, step rates and shorter ground contact times. However, there were relatively few systematic differences in segment/joint angles of the trunk, thigh and knee between the slowest and fastest trials. The findings of Keogh et al. (2010b) suggest that the ability to generate large propulsive anteroposterior forces and impulses during relatively short periods of ground contact is critical for successful heavy sled pull performance.

Sprinting performance is largely dependent upon the propulsive force provided by the extensors of the hip, knee, and foot (Kraemer, Ratamess, Volek, Mazzetti, & Gomez, 2000). Improving strength levels could allow for the production of greater force and decreased ground contact time, leading to a possible increase in stride rate (Spinks, Murphy, Spinks, & Lockie, 2007). Research has suggested that increases in stride rate and stride length may occur via the production of greater propulsive horizontal (anterior-posterior) forces and impulses (Brughelli, Cronin, & Chaouachi, 2011; Hunter, et al., 2004). Hunter and colleagues (2004) suggested that athletes who wish to increase sprint performance should direct most of their training effort into producing a high horizontal ground reaction impulse (GRI), not vertical GRI, thereby allowing both a long step length and high step rate. They supported this view from reports that better sprinters have a lower vertical velocity of take-off, shorter ground contact times and both long step lengths and high step rates (Brughelli, et al., 2011; Kivi, 1999; Mann & Herman, 1985). Such views would support the use of heavy sled pulls to increase sprint performance.

The manner in which a sled pull is performed can alter the biomechanics of the movement and hence the likely adaptations to such training. Specifically, research has demonstrated that the type of harness and cord length will influence the angle of pull and the direction of force applied to the athlete, hence changing sprint kinematics (Alcaraz, Palao, Elvira, & Linthorne, 2008; Cronin, Hansen, Kawamori, & McNair, 2008). A higher harness attachment will produce greater torque around the hips, and a greater forward lean would be required to counteract the applied load. Therefore, the heavy sled pull using a shoulder harness 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 braking 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 of the sprint specific motor units. However, although resisted sprinting is believed to increase lower-limb strength, there are concerns that weighted sled towing (with loads greater than 20% body mass) may not transfer to acceleration performance because of negative influences on acceleration kinematics (Mouchbahanui, Gollhofer, & Dickhuth, 2004; Murray, et al., 2005). Research has demonstrated that resisted sled towing causes acute alterations in sprint kinematics of the early acceleration phase (Letzelter, Sauerwein, & Burger, 1995; Lockie, Murphy, & Spinks, 2003). Kinematics such as stride rate and stride length have been reported to decrease, whereas stance time, trunk and hip angles have been reported to increase as a consequence of this training method (Letzelter, et al., 1995; Lockie, et al., 2003; Mouchbahanui, et al., 2004). It is highly likely that sprint kinematics during the heavy sled pull would be even more amplified. Research into the acute and chronic effects of the heavy sled pull needs to be conducted, so that conditioning coaches have a greater understanding of the potential applications, expected training responses and the possible injury risks inherent to this form of training.

2.7 Injury Risks of Strongman Implement Training

The sport of strongman is similar to the sports of weightlifting and power-lifting in which the athletes lift maximal loads, thus subjecting their musculoskeletal system to immense stresses. It could be argued that due to the complex movements and heavy loads used in strongman events that this type of training could put athletes at greater risk of injury, especially athletes who are new to this mode of training. Strongman events such as the Yoke walk, farmers walk and truck pull are total body movements that may involve periods of unilateral and bilateral ground contact and require the production of horizontal as well as vertical ground reaction forces. In contrast, power-lifting and weightlifting events such as the squat and clean and jerk (respectively) are predominantly bilateral and vertical in nature, requiring the production of large vertical ground reaction forces only.

Injury epidemiology has been examined in power-lifting (Brown & Kimball, 1983; Goertzen, et al., 1989; Haykowsky, et al., 1999; Keogh, et al., 2006; Raske & Norlin, 2002), weightlifting (Calhoon & Fry, 1999; Konig & Biener, 1990; Kulund, et al., 1978; Raske & Norlin, 2002; Ren, et al., 2000) and bodybuilding (Eberhardt, et al., 2007; Goertzen, et al., 1989). While these studies provide critical information about common types of injury and some insight into causation, no such study has been undertaken with strongmen. To date, only one injury case study has appeared in the scientific literature on the sport of strongman (George, 2010). The subject in this case study was a 38-year-old right-hand-dominant strongman competitor who while attempting a 300 lb (~135 kg) overhead axle press sustained a simultaneous acute supraspinatus tear and a distal biceps rupture. While acute rotator cuff tear is commonly associated with tearing of the proximal biceps tendon (Singaraju, et al., 2008), such an injury had never been reported to occur simultaneously with a distal biceps tendon rupture. Although only a case study, this injury may demonstrate that strongman athletes may be prone to potentially serious acute injuries that are not seen commonly during other physical activities.

Researchers have investigated the most commonly injured anatomical locations in power-lifting and weightlifting. The most commonly injured anatomical locations in power-lifting (which consists of the squat, deadlift and bench press) were shoulder, lower back, knee and elbow (respectively) (Keogh, et al., 2006; Raske & Norlin, 2002). Whereas the most frequently injured sites in weightlifting (which consists of the snatch and clean and jerk) were the knee, shoulder, lower back, wrist/hand and elbow (Calhoon & Fry, 1999; Raske & Norlin, 2002). The subtle differences between these sports may reflect between-sport differences in the type of exercise and the manner in which these exercises are performed. For example, power-lifters may be placing their lower backs at greater relative risk during low bar back squats and deadlifts due to their more horizontal trunk position and the very heavy loads used. Researchers have demonstrated that these exercises produce exceedingly large hip extensor torques (Brown & Abini, 1985; Cholewicki, McGill, & Norman, 1991; Escamilla, et al., 2000) and compressive or shear lumbar forces (Cholewicki, et al., 1991; Fortin & Falco, 1997). Other known factors that have been reported to contribute to lower back injury are; excessive spinal flexion, lack of intra-abdominal pressure and an imbalance in the coordination of trunk muscle recruitment patterns to stabilise the spine through antagonistic coactivation (Cholewicki, Juluru, & McGill, 1999; Cholewicki, et al., 1991; Grenier & McGill, 2007; Vera-Garcia, Brown, Gray, & McGill, 2006).

Weightlifters may be placing their knees at greater relative risk performing front squats, clean and jerks and snatches due to the more acute knee angle and larger anterior tibial translation at the bottom of the catch phase (Keogh, 2010b). Heavy loading accompanying deep knee flexion (angle exceeding 90^{o}) places significant load (torque) on the knee particularly on the thinnest part of the femoral cartilage (Reeves, Laskowski, & Smith, 1998b) and on the patella tendon (Kurland, 1982). Weightlifters may also be at risk of patellofemoral osteoarthritis (Kujala, et al., 1995).

Researchers have demonstrated that the shoulder is a commonly injured region among power-lifters, weightlifters and bodybuilders. This may be due to glenohumeral joint being vulnerable to excessive instability because of the lack of bony congruency (Durall, Manske, & Davies, 2001). Exercises such as the overhead press and bench press may contribute to many acute and chronic shoulder injuries. Overhead shoulder presses performed behind the neck places the rotator cuff in an unfavourable position which can irritate the rotator cuff tendons and can cause greater instability (Neviaser, 1991). The bench press places large stresses to the rotator cuff, acromioclavicular joint and shoulder capsule (Fees, Decker, Snyder-Mackler, & Axe, 1998; Reeves, Laskowski, & Smith, 1998a). The repetitive use of these exercises could lead to chronic injuries (e.g. chronic tendinitis) over time (Neviaser, 1991).

The rate of training injuries per 1,000 hours (training injuries·1,000 h^{-1}) are similar between the sports of weight lifting and power-lifting (range 2.7 to 5.8 training injuries·1,000 h^{-1}) (Brown & Kimball, 1983; Calhoon & Fry, 1999; Keogh, et al., 2006; Raske & Norlin, 2002) but lower in the sport of bodybuilding (Eberhardt, et al., 2007) (1.0 training injuries·1,000 h^{-1}). The differences between these sports may reflect the manner in which the lifts are performed. Weightlifters and power-lifters generally train with very heavy loads (i.e. ≥ 85% of 1RM) as their goal is to increase maximum strength. As there is a tolerance load of a certain magnitude in human tissue, increased mechanical loading on the musculoskeletal system can be an inciting factor for injury (Keogh, 2010b). Studies on weightlifters and power-lifters have generally shown a higher proportion of acute than chronic injuries, and injuries are generally muscle sprains and strains (Calhoon & Fry, 1999; Keogh, et al., 2006; Raske & Norlin, 2002). In contrast, bodybuilders typically train with loads of 60 to 80% of 1RM to elicit hypertrophic responses. Such workouts require very high volumes of work. As a result, bodybuilders may suffer more chronic-type connective-tissue injuries such as bone and tendon injuries. As Keogh (2010b) reported subtle-moderate differences in the injury epidemiology of power-lifting, weightlifting and bodybuilding, it is likely that strongman training would also have somewhat unique injury risks and epidemiology due to the various types of exercises, volume and mechanical work performed. However, such a contention needs investigation.

2.8 Training Practices of Strongman Athletes

One of the most recent strongman studies examined the training practices of 167 strongman competitors using a 65-item online survey (Winwood, et al., 2011), adapted from a similar study involving British power-lifters (Swinton, Lloyd, Agouris, & Stewart, 2009). The subjects consisted of 83-local, 65-national and 19-international level strongman competitors. Winwood and colleagues (2011) reported that all of these strongman athletes performed traditional gym based resistance exercises (i.e. squats and deadlifts) as a regular part of their strongman training. This result may indicate the importance of traditional exercises for building the foundation of strength. The study demonstrated that 74% of these athletes commonly performed hypertrophy training, 97% performed maximal strength training, and 90% performed power training. Power training methods included the use of bands, compensatory acceleration methods, lower body plyometrics, and Olympic lifts and their derivatives. Eighty percent of these athletes incorporated some form of periodisation in their training which was lower than that previously reported in elite British power-lifters (96.4%) (Swinton, et al., 2009), but similar to those reported by major league baseball strength coaches (85.7%) (Ebben, Hintz, & Simenz, 2005) and National basketball strength coaches (85.0%) (Simenz, Dugan, & Ebben, 2005). While these findings of Winwood et al. (2011) demonstrate many similarities of strength and power training methods between strongman competitors, weightlifters and power-lifters, 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. Some examples were 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. However, it is still not known what intensities these athletes trained at (i.e. heart rate training zones, power outputs and work-to-rest ratios etc.).

Interestingly, the findings of Winwood et al. (2011) revealed differences in how the strongman incorporated strongman events training into their overall programme. 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. 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 were most favoured. It may be because these are the most common lifts in strongman competitions. Another reason could be the accessibility of these training implements and the different types of stress that these events place on the body’s systems (McGill, et al., 2009) and perhaps exercises that transfer readily to other strongman events offering similar challenges. For example, the log press may transfer to other less common overhead events such as the axle or dumbbell clean and press, whereas the farmers walk may provide some carryover to other carrying events such as the yoke walk or keg carry.

The open ended question at the end of the survey in the study by Winwood and colleagues (2011) also provided further 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. Specifically, the type of events (i.e. one repetition maximum or maximum repetitions event) in a competition can determine training loading strategies, with competitors determining the most efficacious training protocols for each event. Comprehensive reviews of literature have demonstrated that different training protocols can elicit different mechanical, hormonal, and metabolic stresses on the human body and hence result in varying chronic responses (Crewther, et al., 2005; Crewther, Cronin, & Keogh, 2006a; Crewther, Keogh, Cronin, & Cook, 2006b). While the effects of traditional training protocols on physiological responses are well documented, little evidence exists as to the acute and chronic physiological effects of strongman training.

2.9 Strength, Anthropometrics and Strongman Performance

Recently, Winwood and colleagues (2012) examined the interrelationships 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 competition 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 found in the study by Winwood et al. (2012) 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 overall successful strongman performance. Of the 1RM strength measures the squat and bench press demonstrated the highest interrelationships with overall strongman competition performance (r = 0.85 and r = 0.78) respectively. Previous research has shown significant relationships between bench press strength and grinding performance in Americas Cup sailors (Pearson, Hume, Cronin, & Slyfield, 2009) and between squat strength and sprinting ability (McBride, et al., 2009). Interestingly, there were clear large to very large relationships (r = 0.61 to 0.85) between 1RM squat strength and performance in each of the four strongman events and overall completion placing, indicating the importance of maximal squat strength to successful performance across many strongman events. Clear moderate to very large correlations were also demonstrated between body mass and all aspects of strongman performance (r = 0.45 to 0.73), further suggesting the importance of a high body mass. Interestingly, the study by Winwood and colleagues (2012) found that low and trivial relationships existed between height and all measures of strongman performance. Although a limitation of this study was that no measures of trunk or limb lengths were obtained, the lack of correlation between height and strongman performance suggests that these factors are not overly important 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 as it could be theorised that by being taller and having a longer torso and arms may allow for greater leverage for the tyre flip. While no studies have investigated the relationship between body segment (lever) lengths and strongman event performance, studies have examined the correlation between lever lengths and 1RM performance. The start of the tyre flip appears similar to the posture employed at the beginning of a deadlift. However, only one study has demonstrated moderate and large correlations of leg length (r = 0.39) and height (r = 0.55) to 1RM deadlift strength (Mayhew, McCormick, Piper, Kurth, & Arnold, 1993a), while other studies have reported trivial to low relationships (r = -0.07 to 0.16) (Mayhew, Piper, & Ware, 1993b, 1993c).

The bench press is another example where it is often thought that shorter arms would be more beneficial for 1RM strength performance. However, studies have demonstrated a range of low and trivial relationships between upper arm length (r = -0.05 to 0.13) and lower arm length (r = -0.14 to 0.12) to bench press performance

(Hart, Ward, & Mayhew, 1991; Keogh, Hume, Mellow, & Pearson, 2005; Mayhew, Ball, Bowen, & Prudhomme-Lizotte, 1989; Mayhew, Ball, Ward, Hart, & Arnold, 1991). Interestingly, the study of Hume and colleagues (2003) reported that heavyweight power-lifters are generally taller than their lightweight counterparts and as a result have longer limbs. However, the tendency for a longer limb decreasing strength by increasing the moment arm and resistance torque of the load may be offset by an increase in the girth and cross-sectional area of the muscle (Hume, et al., 2003). Numerous studies have demonstrated moderate to very large relationships ($r = 0.38$ to 0.82) between muscle girths and cross-sectional area to 1RM strength performance (Brechue & Abe, 2002; Hart, et al., 1991; Keogh, et al., 2005; Mayhew, et al., 1989; Mayhew, et al., 1991; Mayhew, et al., 1993a; Mayhew, et al., 1993b, 1993c; Peterson, et al., 1996) which may suggest that girths and muscle cross sectional area are better indicators for strength performance than lever lengths.

In support of the proposed greater importance of muscular girths than lever lengths, Winwood and colleagues (2012) demonstrated that flexed arm girth and calf girth were most highly interrelated with strongman competition performance ($r = 0.79$ and $r = 0.70$ respectively) and 1RM bench press performance ($r = 0.82$ and $r = 0.67$ respectively). The results could reflect the importance of the arms and calves as primary agonists in these exercises. Larger muscles have a greater potential to produce force which is beneficial for strength performance (Brechue & Abe, 2002; Keogh, Hume, Pearson, & Mellow, 2009; Komi, 1979). Weaknesses in the calves or arms could also limit the transfer of force produced from the larger muscle groups and prove to be a weak link that limits performance. While results of Winwood and colleagues (2012) established that body structure and common gym based exercise strength are meaningfully related to strongman performance in novice strongman athletes, additional research is required to better understand this relationship, especially in more experienced competitors.

2.10 Training Studies

Currently, training studies on the effectiveness of strongman implements as a conditioning method are extremely limited. To date, no training studies involving standard strongman implements have been performed, although training studies have been reported on the non-traditional implement the ‘kettlebell’. Similar to strongman exercises; kettlebell exercises involve both horizontal and vertical motion e.g. the swing. The kettlebell is a round cast iron weight with a handle. The unique design of the kettlebell allows its centre of mass to extend beyond the hand which facilitates full body ballistic movements (Manocchia, Spierer, Lufkin, Minichiello, & Castro, 2013). In recent years the kettlebell has re-emerged as a popular option for athletic conditioning and is used across a broad spectrum of strength and conditioning programmes, from novice users to elite level athletes (Manocchia, et al., 2010). Kettlebells (known as *girya*) have been a popular training tool in Russia for many years and date back to 1704 (Tsatsouline, 2006). Advocates of kettlebell training have suggested that kettlebells can be used to increase muscular strength, muscular endurance, cardiovascular fitness and reduce body fat (Tsatsouline, 2006). This has been supported by recent research that found kettlebells provided a sufficient stimulus to increase cardiovascular fitness (average %HRmax = 86.8 ±6.0%), power (2.2 to 19.8%) and maximum strength (9.8 to 35.6%) in recreationally trained participants (Farrar, Mayhew, & Koch, 2010; Lake & Lauder, 2012b; Manocchia, et al., 2013; Otto, Coburn, Brown, & Spiering, 2012).

Manocchia and colleagues (2013) examined the effects of a 10-week kettlebell programme performed twice a week on 23 male and female recreationally trained participants. While no significant differences were observed in the vertical jump in comparison to the control group (n=14), significant differences ($p < 0.05$) in the magnitude of improvements were apparent in the clean and jerk (34.9 ± 3.6 kg to 39.1 ± 3.8 kg) and bench press (39.9 ± 22.6 kg to 54.1 ± 30.3 kg). It would seem that kettlebells may be an effective tool to improve performance in the sports of weightlifting and power lifting for novice participants.

In contrast to the study of Manocchia et al. (2013), Otto and colleagues (2012) found that short term kettlebell training (12 training sessions for more than 6 weeks) significantly increased vertical jump height in 17 recreationally trained men. This study was limited in the fact that that the participants reported little or no experience performing weightlifting and kettlebell exercises. The study found that the gain in vertical jump height performance (2.2%) was equivalent to that achieved by the weightlifting and traditional heavy resistance training group (n=13). While kettlebells were not as effective as weightlifting in increasing maximal strength (Otto, et al., 2012) it has been reported that common kettlebell exercises (e.g. kettlebell swing) have a considerable horizontal force component, which could have important implications for the majority of athletes whose sport requires fast and/or powerful horizontal movements (Lake & Lauder, 2012a). Kettlebell training may also have benefits over traditional and weightlifting movements such as ease of teaching, limited space, cost and less intimidating.

Recent research comparing back squats and jump squats with the mechanical demands of the kettlebell swing (Lake & Lauder, 2012a) found that peak and mean force tended to be greater during back and jump squat performances. However, kettlebell swing peak (2371 to 3281 W) and mean power (1130 to 1683 W) were greater than the back squat peak (1798 to 2192 W) and mean power (823 to 983 W) and was largely comparable to jump squat peak (2192 to 3468 W) and mean power (983 to 1682 W) performances. Such a result suggests that the kettlebell swing may be a useful addition to elicit increases in power and explosive strength. Lake and Lauder (2012b) tested this hypothesis using 24-subjects with three months resistance training experience. Subjects were randomly assigned to either a kettlebell or jump squat training group and trained twice a week for six weeks. The kettlebell group performed 12 rounds of 30-second kettlebell swing exercises with each set separated by a 30-second rest. Kettlebell loading was determined by bodyweight (i.e. 12 kg if <70 kg or 16 kg if >70 kg). The jump squat training group performed at least 4 sets of 3 jump squats with the load that maximised peak power. Training volume was altered to accommodate different training loads and ranged from 4 sets of 3 with the heaviest load (60% 1RM) to 8 sets of 6 with the lightest load (0% 1RM). The kettlebell training group improved maximum half squat strength by 12% (ES = 0.81) compared to 8% (ES = 0.43) for the jump squat training group. Conversely, the jump squat group demonstrated greater vertical jump height (24% versus 15%) improvements (ES = 0.83) than the kettlebell training group (ES = 0.60). Interestingly, no significant differences in maximum strength and explosive strength were apparent between the two training groups. It appears that 6-weeks of bi-weekly kettlebell training is a sufficient stimulus to increase both maximum and explosive strength and offers a useful training alternative to strength and conditioning professionals. Future research is needed to determine the effect of kettlebell swing training on horizontal explosive strength movements, like the broad jump and sprint performance. Future training studies could use well trained participants as it is problematic to extrapolate findings from novice weight training subjects to more experienced weight trainers. Researchers have suggested that initial strength increases for novices will occur rapidly as a result of almost any resistance training method (Chestnut & Docherty, 1999; Wilson, 1993).

2.11 Conclusion

The limited research on strongman provides us with some preliminary understanding of the stress these exercises place on the human body and the potential training applications and risks. Needs analyses of most strongman events would suggest they are functional exercise performed in multiple planes in an upright position. Many of the strongman events such as the truck pull, farmers walk and yoke walk are unilateral exercises which require the production of horizontal as well as vertical unilateral forces. These carrying events place high demands on the body's core musculature so should be carefully integrated in an athlete's periodised plan. Cross-sectional studies suggest that events such as the heavy sled pull and truck pull may help athletes improve sprint start and acceleration capabilities as well as their success in contact situations characterising American football and the rugby codes. However training studies are needed to support this hypothesis. The recent training studies on kettlebells have demonstrated that kettlebells are a sufficient stimulus to increase both maximum and explosive strength in recreationally trained subjects.

The literature demonstrated the high physiological demands required in strongman exercises such as the truck pull/push and tyre flip, hence suggesting that these events could prove useful in improving anaerobic conditioning and for increasing energy expenditure. Strongman training may be also beneficial for improving muscular hypertrophy. The integration of strongman events for conditioning a group of athletes can present some challenges as loads need to be applied to suit the level for each individual. Strength and conditioning coaches must also consider the type of strongman events they wish to integrate into the conditioning of their athletes as different strongman events produce different types and levels of stress and muscle activation.

For athletes wishing to compete in the sport of strongman, the literature demonstrated that strongman athletes incorporate conditioning practices that are focused on increasing muscular size, the development of maximal muscular strength, power and endurance as well as anaerobic conditioning. System force (body mass + 1RM squat), calf and maximum flexed arm girth and proficiency in the tyre flip may be the best indicators for strongman performance, at least those involving novice strongman athletes. The studies suggested that strongman athletes need power through mid-range (Keogh, et al., 2010c), metabolic conditioning (Berning, et al., 2007; Keogh, et al., 2010c) and high core and hip abduction strength, stability, grip strength and high levels of fat free mass and overall strength (McGill, et al., 2009; Winwood, et al., 2012). Unfortunately, the experimental studies do have limitations in regard to their small subject numbers, most of whom would be considered regional-level athletes. 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.

2.12 Directions for Future Research

Many practitioners are writing articles and books that advocate the use strongman-type exercises in their athletes' conditioning programmes (Baker, 2008; Bennett, 2008; Corcoran & Bird, 2009; Hedrick, 2002, 2003; Poliquin & McDermott, 2005; Waller, et al., 2003), but the evidence base still remains limited. A scientific understanding of this type of training is needed before strength and conditioners find reason to neglect current training strategies that are proven through research. Future research should focus on the following areas:

How strongman implements are currently utilised by strength and conditioning coaches. Coaches and athletes will benefit from such an analysis by gaining some indication of how to best incorporate strongman implement training into their resistance training programmes to help maximise performance enhancements.

The possible injury potential associated with this form of training warrants attention. Studies investigating the injury epidemiology of strongman would offer comprehensive information about the possible risks associated with strongman type training; thereby allowing the strength and conditioning specialist to better understand its risks in relation to the literature and other forms of training such as power-lifting or weightlifting.

Further research is needed to examine the biomechanics of strongman exercises and to examine the kinematic and kinetic differences between strongman exercises and traditional based exercises. Such data could help guide programming and give support to the use of strongman type exercises in strength and conditioning programmes. Furthermore such data would help equate loading in subsequent training studies.

Research should also continue to investigate the physiological stress (i.e. metabolic and endocrine responses) strongman training places on the body's systems. Such data would give strength and conditioning coaches and sport scientists a greater understanding of the acute stresses that strongman training imposes on the system and the likely chronic effects.

Finally, longitudinal studies are needed to determine the chronic effect of strongman type exercises. These studies may involve a comparison of strongman event vs conventional training as well as how the inclusion of some strongman exercises into a conventional conditioning programme may differ to that of traditional type gym based approach in improving performance capabilities.

Currently, the peer-reviewed scientific literature on the sport of strongman is quite limited. While it would appear that many strength and conditioning practitioners and athletes are starting to use strongman type exercises to enhance athletic performance, it would be imperative to have an understanding of the stresses that this form of training places on the body and of the possible benefits and potential risks associated with these exercises.

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CHAPTER 3. STRONGMAN IMPLEMENT USE IN STRENGTH AND CONDITIONING PRACTICE

3.1 Prelude

In recent years, the use of strongman training modalities have become popular in strength and conditioning practice (Bennett, 2008; Corcoran & Bird, 2009; Ebben, et al., 2004; Hedrick, 2002, 2003, 2007; Zemke & Wright, 2011). Strength and conditioning coaches have proposed that strongman exercises are more functional than traditional training approaches. Strongman type exercises are total body movements performed in horizontal and vertical directions. Hence, they may better replicate sporting movements and place greater demand on the body's core musculature than other resistance training approaches. However, no peer-reviewed literature has examined how strongman implements are utilised in strength and conditioning practice. Thus, strength and conditioning coaches have little evidence on which to inform the inclusion of strongman implement training into the training of their athletes. Therefore the purpose of this study was to gain some insight into how strongman implements are being utilised in strength and conditioning practice. It was thought that an analysis of strongman implement training in strength and conditioning practice would provide a more detailed understanding of how these implements are used in professional practice. This information will be useful for strength and conditioning coaches who may consider using some strongman implements in the conditioning programmes of their athletes.

Winwood, P. W., Cronin, J. B., Keogh, J. W. L., Dudson, M. K., & Gill, N. D. (In Press). How coaches use strongman implements in strength and conditioning practice. *International Journal of Sports Science & Coaching*.

3.2 Introduction

Strongman implement training to enhance sport performance is becoming increasingly utilised amongst strength and conditioning practitioners (Baker, 2008; Corcoran & Bird, 2009; Hedrick, 2003; Poliquin & McDermott, 2005; Zemke & Wright, 2011) despite the paucity of research addressing this type of training. Strongman type exercises are total body movements performed in multiple planes. Hence, they may better replicate sporting movements and place greater demand on the body's core musculature than other resistance training approaches. Such a contention is supported by the findings of McGill and colleagues (2009), where exceedingly high degrees of core and hip abductor activation in many common strongman exercises were reported.

Hedrick (2003) suggested that in many sporting situations, athletes encounter dynamic resistance (e.g. changing resistance in the form of an opponent) as compared to constant resistance (such as machines or free weights). Strongman implements like water-filled kegs may give the opportunity for athletes to train against a dynamic resistance rather than a constant resistance typical of a barbell or dumbbell (Hedrick, 2002). It has been proposed that incredible levels of strength and muscular development can be achieved by combining common weight training exercises such as the squat and deadlift with the lifting of heavy, awkward, hard to manage objects such as beams, barrels, logs, sandbags or kegs (Kubik, 1996).

While several strength and conditioning practitioners have made some suggestions on what strongman implements could be incorporated in strength and conditioning programmes of non-strongman athletes (Bennett, 2008; Hedrick, 2003; Waller, et al., 2003; Zemke & Wright, 2011), very little research has examined how strongman training techniques are actually used. To date, only two studies have investigated strongman implements in strength and conditioning practice (Baker, 2008; Winwood, et al., 2011). While these studies give valuable insight into the difficulty in personalising strongman training loads with large groups of athletes, and how strongman competitors train for strongman competitions (respectively), no research has examined how strength and conditioning coaches incorporate strongman implements into the training of their athletes. Thus, strength and conditioning coaches have little empirical evidence on which to inform the potential inclusion of strongman implement training within their programming practice. Such studies have been conducted into other areas of strength and conditioning practice, with published surveys examining the resistance training practices of strength and conditioning coaches in hockey (Ebben, et al., 2004), baseball (Ebben, et al., 2005), basketball (Simenz, et al., 2005), rowing (Gee, et al., 2011), United States high schools (Duehring, Feldmann, & Ebben, 2009) and the National Football League (NFL) (Ebben & Blackard, 2001). These studies offer a source of collective ideas that others can compare and incorporate into their own strength and conditioning practice.

Therefore, the purpose of this study was to describe how strongman implements are currently utilised by strength and conditioning coaches to enhance athletic performance. Coaches will benefit from such an analysis by gaining some insight of how to best incorporate strongman implement training into their athletes' resistance training programmes. In addition, the knowledge gained may help guide future research on the efficacy of strongman implements on muscular function and performance.

3.3 Methods

3.3.1 Approach to the Problem

A comprehensive strongman implements use survey was administered online and aimed at identifying how strength and conditioning coaches used strongman implements in their athlete's strength and conditioning programmes and why these implements were used. The research hypothesis was that the majority of coaches responding to the survey would integrate strongman implements into their athlete's strength and conditioning programmes and coaches would have a variety of reasons for its use.

3.3.2 Participants

Two hundred and twenty strength and conditioning coaches (211 male and 9 female) ((mean ±SD) 34.0 ±8.2 y old, and 9.8 ±6.7 y general strength and conditioning coaching experience) gave informed consent to participate in this study. The participants included coaches of amateur (n = 74), semi-professional (n = 38) and professional (n = 108) athletes. In order to protect the confidentiality of the coaches, no participant's details were associated with the survey. This study was approved by the AUT University ethics committee. In order to meet ethical approval, all questions in the survey were answered on a voluntary basis. As a result, the numbers of coaches responding to each specific question items varied. Participant response numbers are indicated in the results section.

3.3.3 Participant Recruitment and Inclusion Criteria

Coaches were recruited through professional networks and multimedia. The professional networking site 'LinkedIn' was the primary method used to recruit the coaches. A variety of coaches from specific competitions (i.e. National Football League (NFL), National Rugby League (NRL), Super Rugby, National Basketball League (NBA) and Major League Baseball (MLB)) were targeted. Identified coaches were sent a letter via email. The letter contained an invitation to participate in the research and the link to the online survey. An information sheet outlining the objectives and purpose of the study was situated on the first page of the online survey. Participants were asked to indicate their consent by participating in the survey. Surveygizmo.com was used to launch the electronic survey on the internet.

Inclusion criteria were met if participants were identified as being a strength and conditioning coach, were working or had recently worked as a strength and conditioning coach, and had an active e-mail address. Five hundred coaches who met those criteria were sent an invitation to participate in this study. Of those invited to participate, 276 participants (55%) accessed the online survey, which included those that observed the survey, partially completed the survey and the 220 (44%) that "completed" the survey. The criterion for a completed survey was that the participant must have completed at least the first three of four sections of the questionnaire.

3.3.4 Research Instrument

Coaches completed a self reported 4-page retrospective survey. The *Strongman implements used in practice* survey was created for this study based on surveys used with rowers and strongman competitors (Gee, et al., 2011; Winwood, et al., 2011). The original strongman implements survey was pilot tested with University Professors, and strength and conditioning coaches (n = 6) to ensure its ease of use with this population. As a result of pilot testing, the survey was slightly modified including clarifying and improving the wording of a small number of questions before it was available for the main study.

The strongman implement survey consisted of four main areas of inquiry including; background information, resistance training, periodisation and strongman implement use. Background information included questions on age, strength and conditioning coaching experience, type of sport and level of athlete coached, membership to professional bodies and academic qualifications. The resistance training section included questions pertaining to training lengths and frequency and strongman implement use. Participants were requested to detail their common/typical values for each training question. The periodisation section included questions on where strongman implements were used in the periodised plan and what physiological responses were sought. The strongman implement use section, included questions on how strongman implements were used in professional practice. Open and closed questions were used for Sections 1 and 4, with closed questions used for Sections 2 and 3.

The survey required the coaches to provide a description of how they integrate strongman implements in their strength and conditioning practice. A strongman implement was defined as "any non-traditional implement integrated into strength and conditioning practice". Based on this definition, training implements such as tractor tyres, farmers walk bars, sleds, sandbags, kegs, steel logs, stones, ropes and kettlebells were all considered to be strongman implements. Traditional training was defined as "standard exercises performed in the gym by regular weight trainers and strength athletes" (e.g. squat, bench press, power clean, etc.). In order to minimise the limitation that coaches who use strongman implements could have been more likely to complete the survey, all coaches were asked to fill in the survey regardless of whether they used strongman implements.

3.3.5 Statistical Analyses

Means and standard deviations were calculated for the participant characteristics and strongman implement use. Frequencies of responses were collated for questions related to strongman implement use. Categorical and ordinal data were reported as both absolute numbers and as a percentage of total responses. Scores for ranked questions were determined by weighted calculation in Surveygizmo; items that were ranked first scored higher than the following ranks, so that the total score was the sum of all weighted ranks. Weighted calculation was based on the number of options represented. For example, for the 5-option question the weighted sum for the option that was placed in the first position was worth 5-points. The second option chosen was given a score of 4-points and so forth.

Answers to open-ended questions were content analysed by investigators who were experienced with qualitative methods of sports science research and content analysis. During data analysis, investigators generated raw data and higher-order themes via independent, inductive content analysis and compared independently generated themes until consensus was reached at each level of analysis. At the point of development of higher-order themes, deductive analysis was used to confirm that all raw data themes were represented. In some cases, the participants provided greater depth of information that represented more than one concept and hence responses contributed to more than one higher order theme.

3.4 Results

3.4.1 Background Information

Two hundred and twenty strength and conditioning coaches (211 male and 9 female) from 19 countries; United States of America (n = 69, 31%), Australia (n = 52, 24%), United Kingdom (n = 45, 21%), New Zealand (n =18, 8%), various (n = 36, 16%) completed the survey. The coaches listed thirty-eight sports as their primary emphasis with rugby league, American football, rugby union, basketball, baseball and soccer the most common.

Coaches reported possessing a variety of certifications, the most common being the certified strength and conditioning specialist (CSCS) (n = 85); Australian Strength and Conditioning Accreditation (ASCA) (n = 35); USA Weightlifting (USAW) Accreditation (n = 21); United Kingdom Strength and Conditioning Accreditation (UKSCA) (n = 20); and Accredited Strength and Conditioning Coach (ASCC) (n = 17). The majority of strength and conditioning coaches (n = 205) had a degree as their highest level of education. The most common highest degrees were masters (n = 101), bachelors (n = 84) and 13 respondents indicated completing a doctorate.

3.4.2 Strongman Implement Use

Eighty-eight percent (n = 193) of coaches reported using strongman implements in the training of their athletes. Sled pulling/pushing, ropes, kettlebells, tyres, sandbags and farmers walk bars were ranked the top six implements used by coaches (see Figure 3.1).

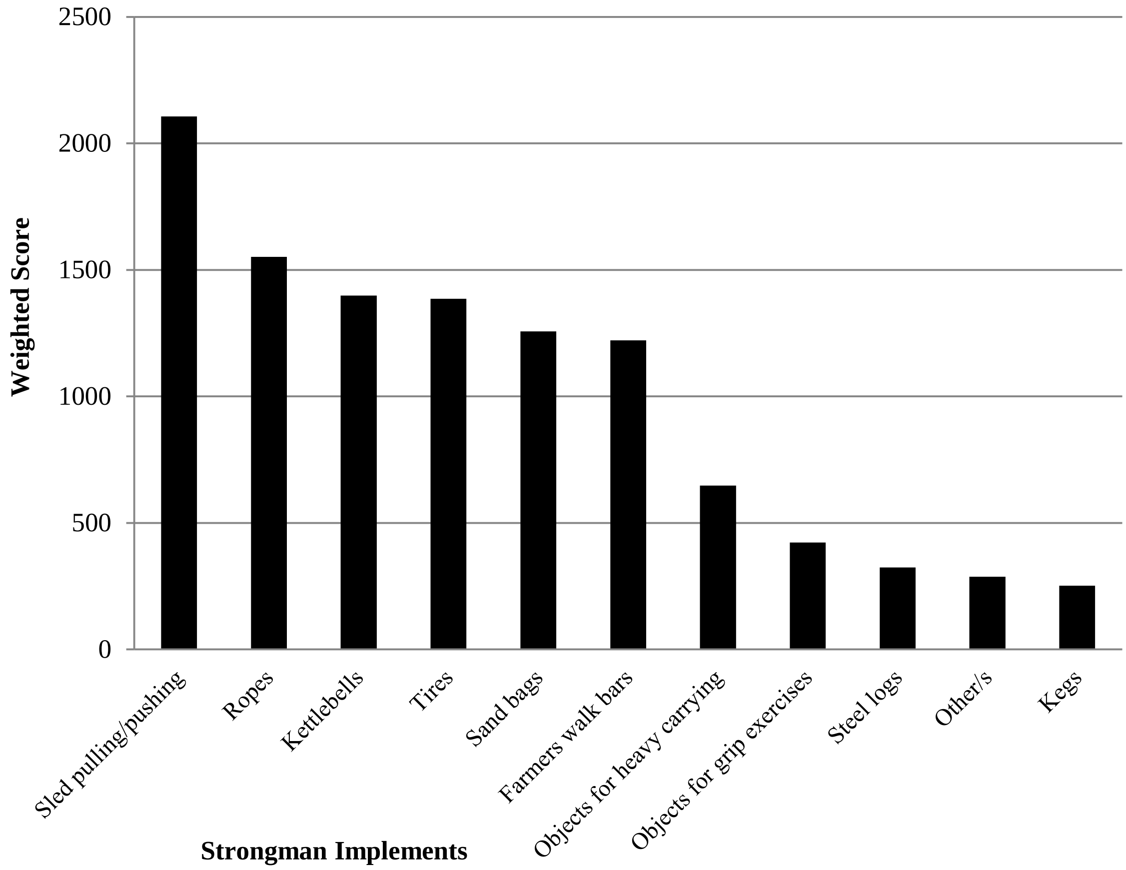

Figure 0.1: Top 11 strongman implements used by coaches (n = 193) in their professional practice.

N.B: The "Other/s" category, included use of heavy medicine balls (up to 200 lb), cars/utes for pushing, sledge hammers, slosh bags and balls, and power clubs.

3.4.3 Why and How Strongman Implements Are Used

Coaches (n = 193) ranked anaerobic/metabolic conditioning, explosive strength/power and muscle endurance as the three main physiological reasons of why they used strongman implements in their athletes training (see Figure 3.2).

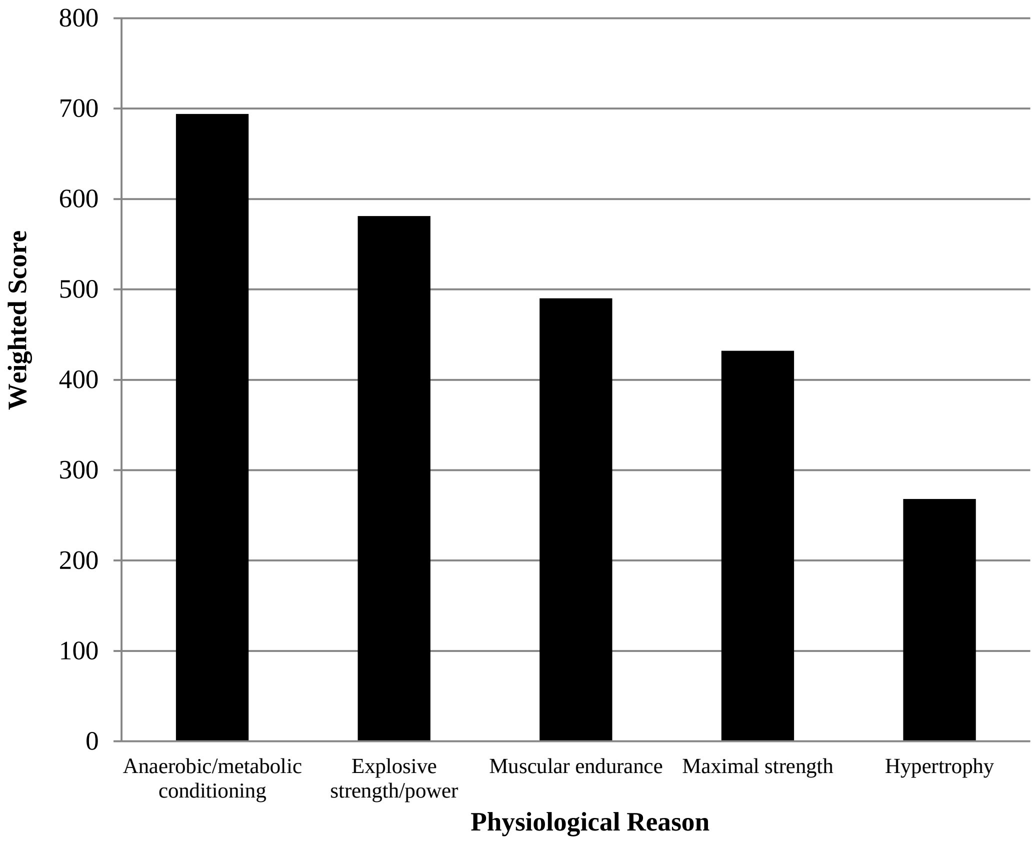

Figure 0.2: Main physiological reasons why coaches (n = 193) use strongman implements.

Of the 193 coaches who reported using strongman implements, 149 coaches (77%) described why and how they used (i.e. training emphasis, reps/distance/time, sets, loading, rest and movement velocity) strongman implements in the training of their athletes (see Table 3.1). A variety of themes were presented which included grip strength, explosiveness, triple extension, hip drive, and core work and stability.

Table 0.1: How strength and conditioning coaches used the top six most common strongman implements (n = 149).

Exercise	Main themes on training emphasis	Reps or distance or time	Sets per session	Loads kg/%BW/%1RM	Rest (sec)	Coaches additional comments	Speed the exercise is performed (% of coaches)
Sled Pushing/ Pulling (n = 135)	Strength, speed, power, muscular endurance, leg and arm drive, acceleration, explosiveness, metabolic conditioning, directional force, reduce axial loading.	23.0 ±11.0 m 17.3 ±7.9 sec	5 ±3	68.0 ±44.3 kg 60.9 ±38.9 %BW	115 ±65 sec	"Load depends on the implement being used, where on the force/velocity curve we're working, and the surface we're moving the implement on. Rest will also vary."	Fast/explosively 70% Moderate 24% Slow 6%
Ropes Climbs/pulls Battling ropes Tug of war (n = 112)	Strength, endurance, power, speed, sports specific, upper body conditioning, low impact conditioning, interval training 1:1 work/rest ratio, shoulder and core work, isometric strength, grip strength.	11.1 ±6.7 reps 13.5 ±2.1 m 37.3 ±20.1 sec	6 ±5	45 ±32.8 kg 37.5 ±3.5%BW Heavy rope (1.5 to 2 inch thick)	77 ±65 sec	"Sets of 20 for 5-10 different movements, bursts of 30sec for power, up to 2 minutes for endurance and mental toughness." "Loading depends on if working on strength, power or muscular endurance."	Fast/explosively79% Moderate 16% Slow 5%
Kettlebells Swings/ Variations (n = 98)	Strength, power, endurance, explosive triple extension, hip thrust and conditioning, hip, trunk and shoulder mobility, grip strength, core work and stability.	15.0 ±10.3 reps 38.3 ±19.7 sec	4 ±2	23.6 ±9.1 kg	78 ±46 sec	"Reps / time dependent on skill execution." "Tabata workout - end of session finisher."	Fast/explosively 73% Moderate 27%

Tyres Flips (n = 98)	Power, strength, endurance, explosive drive from low set, triple extension, hip drive, sport specific, metabolic conditioning.	7.2 ±4.6 reps 18.0 ±7.6 m 63.4 ±46.1 sec	4 ±2	151.1 ±74.6 kg 63.6 ±21.2 %1RM	107 ±58 sec	"Bodyweight for speed flips (metabolic), double bodyweight (power), triple bodyweight (strength)." "Tire - 100kg+ (men) & 60kg (women)."	Fast/explosively 78% Moderate 20% Slow 2%
Sand Bags Throws/ Carries/Clean and jerk/ Get ups (n = 93)	Power, strength, endurance, postural control, functional strength, hip power & rotation, grip work.	10.2 ±5.7 reps 34.4 ±7.2 sec 29.4 ±12.3 m	4 ±2	21.4 ±8.0 kg	80 ±58 sec	"Uneven weight which replicates working against another body." "Used for off-set loads to improve function of obliques, QL, etc." "Foot placement in various positions due to the unstableness of the gravel in the bag."	Fast/explosively 71% Moderate 24% Slow 6%
Farmers Bars Walks/Carries (n = 85)	Total body strength, grip strength, gait loading pattern, trunk, knee, ankle and shoulder conditioning, dynamic core strength and stability, foot speed.	29.1 ±11.5 m 58.6 ±54.6 sec	5 ±4	58.7 ±31.4 kg	109 ±67 sec	"70-80% 1RM or based on times e.g. if cannot complete distance within a certain time, weight may be too great." "Load depends on athlete size and gender."	Moderate 57% Fast/explosively 28% Slow 15%

The two main reasons coaches used strongman implements in the training of their athletes (see Figure 3.3) were to help transfer gym based strength gains into more functional strength, and add variation to their athletes training programmes.

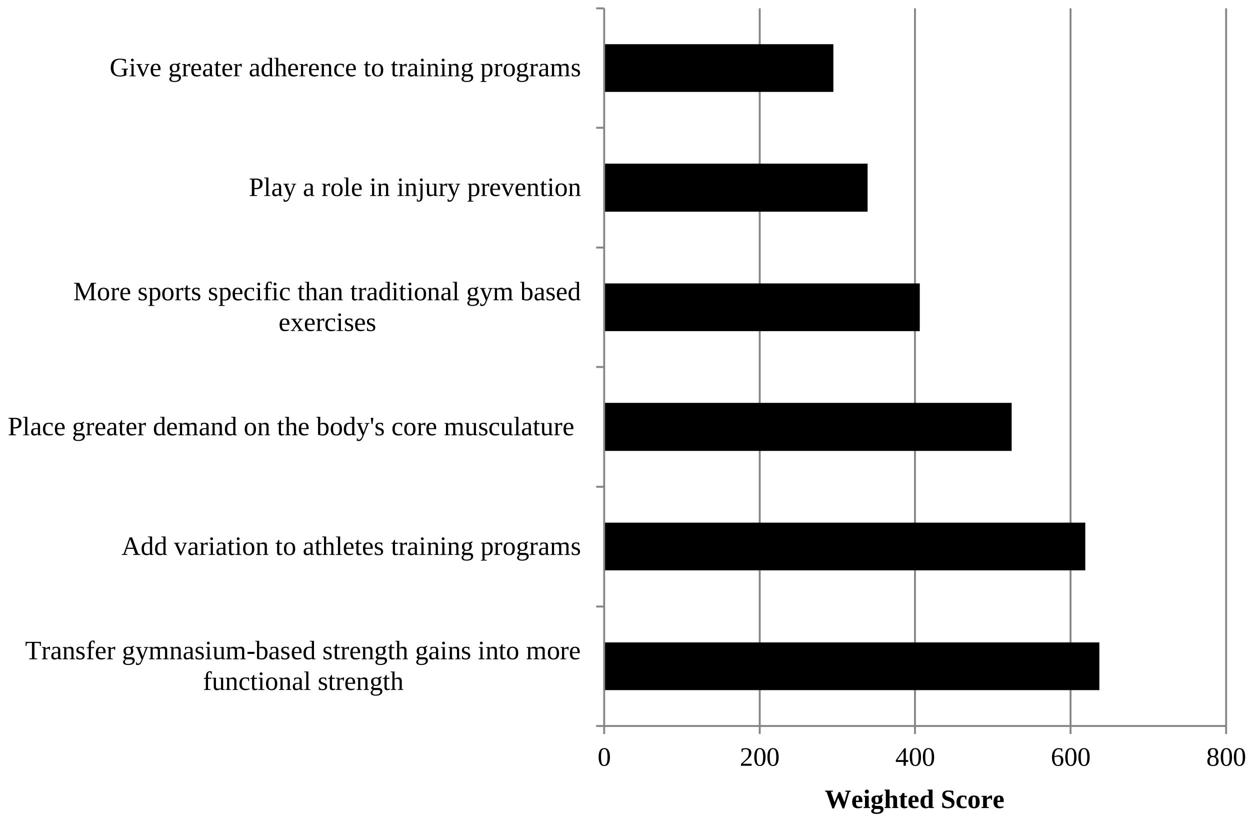

Figure 0.3: Ranking of why coaches use strongman implements (n = 193).

Coaches provided other reasons (that were not mentioned in Figure 11) of why they use strongman implements in the training of their athletes. A summary of these responses is presented in Table 3.2.

Table 0.2: Other reasons for strongman implements use not previously mentioned (n= 98).

Higher-order themes	Responses	Select raw data representing responses to this question
Functional movements	19	"Makes athletes move and deal with strength patterns in different ways."
Competition	15	"Allows you to create competition in the off-season."
Stability	12	"Greater recruitment of core kinetic chains and the resulting stability the athlete gains."
Metabolic conditioning	10	"Strongman training is great for developing lactate tolerance."
Motivation/confidence	9	"I believe it gives athletes confidence to lift and carry objects they don't normally expect to move."
Enjoyment	8	"Incorporating them into training in a competitive way helps to increase intensity of sessions and freshen the athletes with a different 'fun' stimulus."
Grip strength	8	"Great for my baseball guys to develop forearm and hand grip strength to better swing a bat."
Psychological/mental toughness	8	"Gives my athletes the ability to continue to work hard in the face of fatigue."
Athlete learning and development	8	"Reduced time spent learning movements leading to more time spent developing practical strength." "Athletes work together as a team."
Neurological stimulus	6	"Variety in movement planes can assist with stimulating muscle fibers not usually recruited."
Intensity	5	"Very mentally challenging requires 100% effort every single rep."
Training economy	5	"Greater benefits for total body adaptation. Combination of strength and anaerobic work capacity developed simultaneously."
Miscellaneous	27	"Easy to assess areas of weakness as the exercises utilize full body activation, any flaws show up relatively quickly." "When competing in a sport, the body will not always experience forces in a uniform manner, or through a set range. Developing "fringe" abilities helps athletes handle perturbations more effectively." "Minimal eccentric work, which means no soreness post training."

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

Coaches who reported that they did not use strongman implements in the training of their athletes (n = 27) provided reasons or made specific comments of why they chose not to incorporate strongman implements in the training of their athletes. A summary of these responses is presented in Table 3.3. The two main reasons reported were: more effective ways of training and lack of equipment.

Table 0.3: Why strongman implements are not used (n = 27).

Higher-order themes	Responses	Select raw data representing responses to this question
Lack of equipment	9	"I don't have specific strongman implements in my facility at this time."
More effective ways of training	9	"Better gains can be obtained through other methods."
Not specific to the sport	6	"I don't necessarily see it as an important component of cricket specific training."
Limited lifting history	6	"I work with younger athletes and strongman variants may be too advanced for these athletes."
Lack of space	3	"Lack of availability of space."
Time constraints	3	"Time and facilities."
Miscellaneous	4	"The risk is greater than the reward." "The majority of my athletes are young females; as such they are intimidated by this type of training."

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

3.4.4 Where Strongman Implements Are Used

Coaches (n = 193) described the most common environment in which strongman implements were used in the training of their athletes (see Figure 3.4). Strongman implements combined with traditional exercises in a gym based setting was the highest ranked score. Fifty percent of coaches reported that their athletes trained inside with strongman implements.

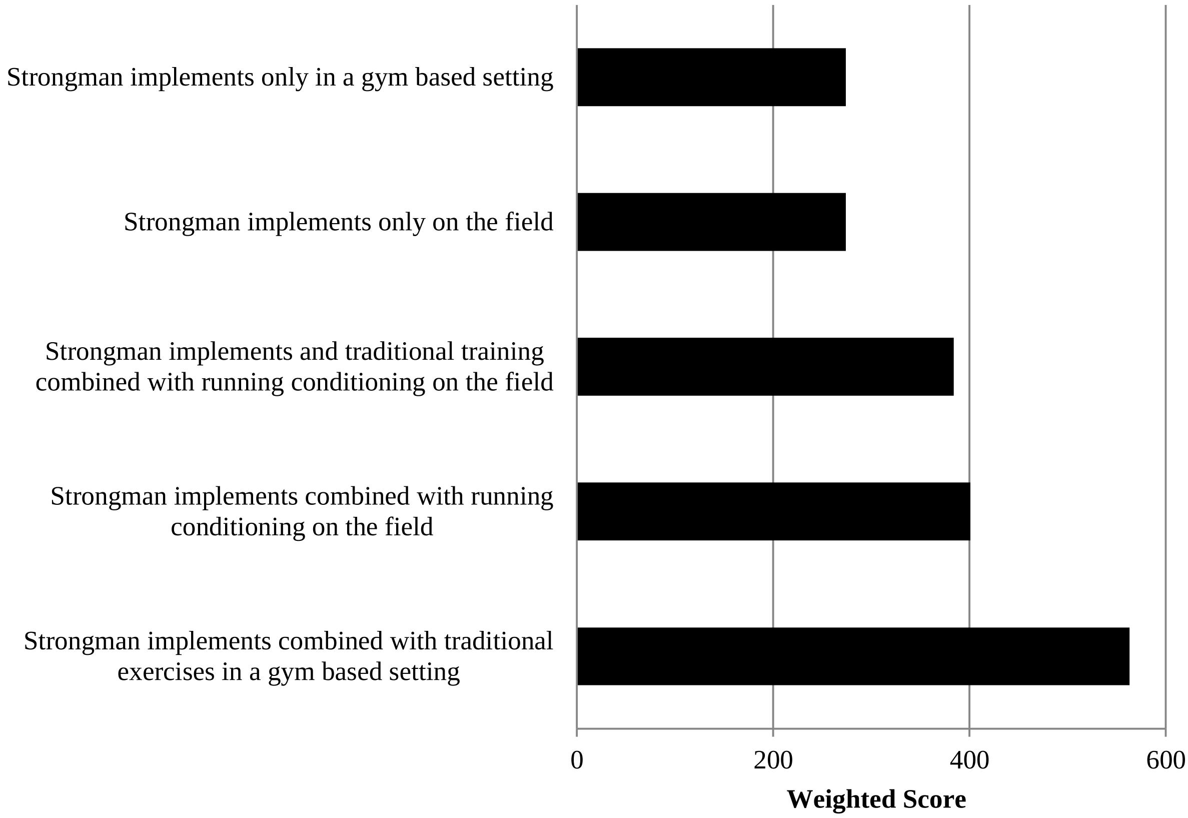

Figure 0.4: Ranking of where strongman implements are used (n = 193)

3.4.5 When Strongman Implements Are Used

Ninety-nine percent (n = 217) of coaches reported using some form of periodisation in their athletes training. Of the 193 coaches who reported using strongman implements, 87% of coaches used them in the general preparation phase, 61% used them in the specific preparation phase and 40% used them in the competitive phase. Sixty nine percent of coaches (n = 133) reported that the general preparation phase was the main phase in which they used strongman implements. Only 7% of coaches reported that the competitive phase was the main phase in which they used strongman implements.

The frequency that strongman implements were used in resistance training by coaches can be observed in Figure 3.5. Once per week was the most commonly reported frequency (29%) by coaches for the use of strongman implements.

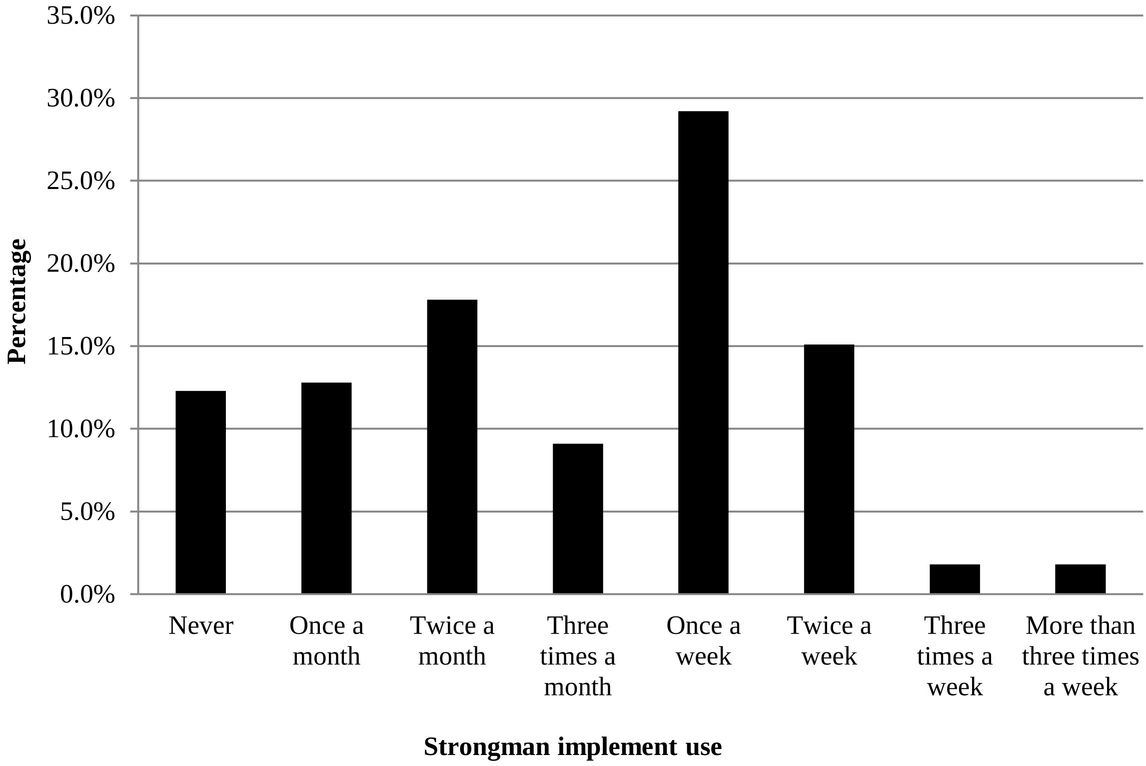

Figure 0.5: How often strongman implements are used by strength and conditioning coaches (n = 220)

3.4.6 Effectiveness of Strongman Implement Training

Coaches evaluated the effectiveness of strongman implement training for their athletes. Forty-nine percent of coaches believed they had achieved good results, 32% believed they had achieved excellent results and 17% believed they had achieved average results from strongman implement training. Of the 193 coaches who use strongman implements in the training of their athletes, 118 coaches (61%) provided elaborative comments about the perceived effectiveness of strongman training on increasing their athlete's performances. A summary of these responses is presented in Table 3.4.

Table 0.4: Elaborative comments about the perceived effectiveness of strongman training on increasing athletes' performances (n = 118).

Higher-order themes	Responses	Select raw data representing responses to this question
Improved motivation/enjoyment	20	"For the athletes the variation from traditional conditioning training has been mentally stimulating."
Uncertain of benefits	16	"Difficult to monitor thus difficult to quantify how much of the athlete's improvement is down to using strongman equipment."
Power and speed gains	17	"They are more powerful and able to unload all their force on the object." "It has worked well for increasing bat speed."
Transfer to actual movements	15	"Superior transfer of skills and strength from gym to sport."
Functionality/specificity	13	"A sled push mimics the drive in a rugby scrum due to body position and knee drive. High correlation into sport."
Effective part of programme	12	"Strongman training is a great tool to add to the tool box."
Variety	11	"It provides variation to training programmes from both a physiological and psychological perspective for athletes."
Strength gains	10	"Strongman training exercises have helped greatly with conditioning and leg strength of my athletes."
Injury reduction	9	"Allows repeated high intensity sessions without the risk of contact." "Injuries due to over lifting and bad techniques have been drastically reduced."
Metabolic conditioning	8	"I generally use strongman implements for creating variety at various stages during the season so the metabolic conditioning aspect from this type of training has elicited heart rates in a desired range for my athlete."
Mental toughness	7	"It tends to place athletes in less comfortable environment than a gym setting. Mental strength is required to get through."
Core	6	"Using strongman implements has helped my athletes involve their core more.
Miscellaneous	38	"Helps promote body awareness producing/reducing forces in less scripted way." "Impossible to know for sure but players seem to retain/steal ball better in contact, stronger over ball." "Both psychological and physiological benefits from this method of training."

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

3.4.7 Disadvantages of Strongman Implement Training

Coaches (n = 118) provided responses to strategies they used to overcome the challenges of using strongman training techniques that allowed the individualisation of training loads when dealing with large groups of athletes. A summary of these responses is presented in Table 3.5.

Table 0.5: Strategies to overcome difficulties in individualising load (n = 118).

Higher-order themes	Responses	Select raw data representing responses to this question
Equipment	54	"Create kegs that are different weights, decide weights on apparatus by bodyweight 1x bodyweight or 2x bodyweight." "Use implements that are scalable (i.e. kettlebells, sleds and climbing ropes)." "We have used two different sized tractor tires and have also used different sized weight plates for our plate punches."
Monitor volume and intensity	47	"Use lighter equipment but getting the stronger athletes to increase the intensity of the exercise through means of more reps, longer duration, unilateral work, and smaller base of support."
Pair or group athletes	29	"Pairing a stronger athlete with a weaker athlete (or male and female athlete together)." "Split athletes into groups, we use first team forwards, first team backs, and then academy as our base line for three training groups."
Planning	6	"Break the athletes into smaller groups, have groups work out at a different time slot."
Regulate usage	4	"If someone has a good training age and can perform the variance of exercises with excellent form then I allow them to perform the exercise(s)."
Miscellaneous	8	"Weighted vests work well as a handicap system." "I don't really try to personalize these workouts."

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

Fifty four coaches found that choosing different sizes of equipment or using equipment that was adjustable (i.e. kettlebells, sleds, farmers walk bars) was the best strategy to overcome the difficulties in individualising load. Coaches (n = 104) provided responses to what other disadvantages they found with using strongman implements compared to traditional training methods. A summary of these responses is presented in Table 3.6. Forty-one coaches believed the logistical demands made strongman implementation difficult.

Table 0.6: Disadvantages of using strongman implements compared to traditional training methods (n = 104).

Higher-order themes	Responses	Select raw data representing responses to this question
Logistical demands makes implementation difficult #	41	"$, storage and logistics of implementing event into training." "Requires space to train. If you have to train outside weather can interfere."
Increased risk of injury	20	"Guys get so caught up in the competitive element that they can forego technique. Also given the multi-planar effect some can find it hard to control the implements as they get tired." "Some exercises may be more dangerous than barbell counterparts (e.g. logs require more lumbar hyperextension than military press, tire flips and stone lifts usually require more lumbar flexion than conventional deadlifts).
Negative impact on movement mechanics	18	"Improper mechanics can be hidden and learned quickly and become habit forming. Athlete must have some base level general weight room coordination and skill to begin strongman training."
Athletes lack knowledge to ensure effective implementation	13	"Athletes have less experience with movements and therefore have to spend extra coaching time to get techniques correct."
Impacts on session efficiency	12	"Having to monitor every athlete for correct technique can extend session time much longer than desired."
Difficulty in achieving buy in of athletes	8	"Apprehension of athletes."
Cost	8	"The cost of new equipment."
Exercises lack specificity	5	"Lack of eccentric contraction minimal knee flexion and hip extension with most exercises."
Miscellaneous	8	"The basics (squat, deadlift, and bench) can be overlooked."

N.B. In some cases, the participant provided information that represented more than one concept and their response contributed to more than one higher-order theme. # Logistical demands refer to: equipment availability, facility capability, storage, time to set up and space.

3.4.8 Additional Information

Coaches (n = 193) were asked if they had any difficulty acquiring and storing strongman implements. Thirty five percent of coaches said they had difficulty acquiring strongman implements and 50% said they had difficulty storing strongman implements. Seventy six percent of coaches believed strongman implement training carried the same risks as traditional training, while 12% believed strongman implement training put their athletes at greater risk of injury than traditional training. Thirty-four coaches answered the last question of the survey which allowed them an opportunity to provide additional data or make specific comments regarding the survey. These responses are detailed in Table 3.7.

Table 0.7: Comments (n = 34).

Higher-order themes	Responses	Select raw data representing responses to this question
Exercise selection and programming	12	"I identify a quality that needs to be developed, Identify a modality that best develops that capacity, and then look to implement it with my time, facility, and professional constraints. For now, unconventional implements fit that bill for the development of certain physical qualities within the team I currently work with."
Risk and coach responsibility	4	"Strongman training doesn't have to be inherently dangerous; a skilled coach knows how to teach the exercises and create programs that work around any pitfalls of strongman training." "I think things like tire flips/ car deadlifts, axle anything is for show. They look fun but the risk versus benefit ratio is way off. The coach must make responsible decisions for his population that will help build the athlete rather than use these implements as novelty for fun or to break their athletes down."
Motivation and fun	3	"Strongman exercises are a great way to get athletes excited about working out. They see strongman competitions on TV and are motivated themselves to compete against one another whether it's flipping tires, holding chains out to their sides or pushing a sled in a

		relay race."
Mental toughness	2	"Strongman sessions can sort the men out from the boys especially in mental toughness."
Concerns about the survey and/or wording of a question	2	"Interesting topic. Survey needs to be broader. Doesn't touch on psychological factors, mental toughness or competitive opportunities that can be instilled via strongman training exercise implementation."
Miscellaneous	11	"As with any endeavour, proper training, persistence, being consistent and exploring ones abilities are critical elements to making progress."
		"If strongman was more effective than traditional, why do "all" strongman train traditional 2-4x wk in the gym? You have to be strong to do strongman training, not use it to get strong."

3.5 Discussion

This is the first survey identifying how strength and conditioning coaches utilise strongman implements in their athlete's strength and conditioning programmes. The majority of coaches (88%) used strongman implements for performance enhancement in the training of their athletes. The three main reasons were; to transfer gymnasium-based strength gains into more functional strength; add variation; and, place greater demands on the core musculature.

The sled (pulling/pushing) was ranked by coaches as the most commonly used strongman implement followed by ropes, kettlebells, tyres, sandbags and farmers walk bars (respectively). Resisted sled pulls using loads of 5 kg and 13% body mass have been shown to improve acceleration performance among rugby players (Harrison & Bourke, 2009) and recreational athletes (Zafeiridis, et al., 2005) however, research on heavy sled pulling is very limited (Keogh, et al., 2010b). Hunter and colleagues (2004) suggested that athletes who wish to increase sprint performance should direct most of their training effort into producing a high horizontal ground reaction impulse (GRI), not vertical GRI, thereby allowing both a long step length and high step rate. The use of sleds may help athletes improve the ability to generate greater sprint momentum over short sprints which is of considerable importance in collision sports that necessitate players bumping off or running through opponents (Baker & Newton, 2008; Keogh, 2010a). In the present study coaches reported that sled pulls were used to develop explosiveness and acceleration capabilities through increased leg and arm drive.

Ropes were used by coaches (75%) to provide shoulder and core work, grip strength and sport specific conditioning. Tug of war, climbs, slams, pulls and battling ropes were rope exercises used by coaches in their athletes' resistance training programmes. The variety of exercises and movement patterns described by coaches demonstrates the versatility of ropes as a conditioning tool to help develop various functional qualities.

Kettlebells were used by coaches to enhance explosive triple extension, hip, trunk and shoulder mobility, and core stability of their athletes. Researchers (Lake & Lauder, 2012b; Otto, et al., 2012) have demonstrated that kettlebells can provide a sufficient stimulus to increase both power and maximum strength in recreationally trained men. While kettlebells were not as effective as weightlifting in increasing maximal strength (Otto, et al., 2012) it has been reported that common kettlebell exercises (e.g. kettlebell swing) have a considerable horizontal force component, which could have important implications for the majority of athletes whose sport requires fast and/or powerful horizontal movements (Lake & Lauder, 2012a). Given the unique training stimulus produced (under very light loading i.e. 12-16 kg), kettlebell training may have some benefits over traditional and weightlifting movements (e.g. ease of teaching, limited space, cost and less intimidating).

Coaches used tyres to develop explosive drive, triple extension and metabolic conditioning in their athletes. Researchers indicated that the tyre flip consists of a first pull, second pull, transition and push phase (Keogh, et al., 2010c). This would appear quite similar to the weightlifting movements as well as jumping in terms of the explosive coordinated triple extension of the ankle, knee and hip joints Coaches may find these similarities important because weightlifting movements and vertical jumping are specific to many athletic skills (Cronin & Hansen, 2005). However, coaches using the tyre flip may be need to exercise some caution as recent research found the tyre flip was responsible for the highest number of bicep injuries among strongman athletes (Winwood, Hume, Cronin, & Keogh, 2014).

Sandbags were used by coaches to enhance functional strength, postural control and hip power and rotation of their athletes. While no scientific evidence exists as the effectiveness of sandbag training for these outcomes, advocates of sandbag training (Santana & Fukuda, 2011; Sell, Taveras, & Ghigiarelli, 2011) have proposed that the unpredictable resistance provided by sandbags forces the body to continually adjust position to maintain stability during functional movement patterns, which may help generate beneficial and event-specific neurological training adaptations.

Coaches ranked anaerobic/metabolic conditioning, explosive strength/power and muscle endurance as the three main physiological reasons of why they used strongman implements in their athlete’s training. Researchers have provided biomechanical and physiological data supporting the contention that strongman events could prove useful in improving strength and power, anaerobic conditioning (through adaptations in lactate production and clearance mechanisms and tolerance levels) and for increasing energy expenditure (Berning, et al., 2007; Keogh, et al., 2010b; Keogh, et al., 2010c).

Different training protocols elicit different mechanical, hormonal, and metabolic stresses on the system and result in varying responses (Crewther, et al., 2005; Crewther, et al., 2006a; Crewther, et al., 2006b). This variety in acute stresses placed on the body was reflected in the wide range of strongman exercise prescription used by coaches with a range of loads (10% to 100% 1RM), distance/reps/time (13 m to 29 m, 7 to 15 reps, 17 to 63 sec) and rest periods (78 to 115 sec) for the top six implements utilised in this study. Regardless of the primary physiological adaptation the coaches were trying to elicit with these exercises, over 70% of coaches instructed their athletes to perform the strongman exercises as fast as possible. An exception to this was the farmers walk, where a slow to moderate speed was instructed by many coaches (73%). The unique challenges provided by this exercise (i.e. gait loading pattern and core strength) may explain the difference in tempo for this exercise.

Eighty-one percent of coaches in this study perceived that strongman implements were good to excellent at eliciting performance gains in their athletes. The coaches also reported that the strongman exercises were useful to include in the overall strength and conditioning programme as they provided improved motivation and enjoyment, power and speed gains, and resulted in greater transference to actual sporting performance than traditional training approaches. However, longitudinal training interventions using strongman implements are needed to substantiate such claims.

Strongman implements were used both indoors and outdoors (50% each) by coaches and in a variety of ways. Coaches reported that the main ways they used strongman implements were in conjunction with traditional exercises in a gym based setting and combined with running conditioning on the field. Such results demonstrate that strongman implements are not used in isolation but are integrated to help supplement a variety of strength and conditioning goals.

Ninety nine percent (n = 217) of coaches in this study reported using some form of periodisation in their athlete's training. This suggests that coaches design their training to emphasise particular adaptations with the goal of increasing physical performance. The majority (69%) of coaches reported that the general preparation phase (pre-season) was the main phase in which they used strongman implements. This result was reflected in the number of sets (4-6 sets) per exercises which indicates the high training volumes associated with this phase (Fleck & Kraemer, 2004). The most common frequency that strongman implements were used in resistance training by coaches in this study was once a week (29%), with large variances being reported in the frequency of use (i.e. once a month to more than three times a week). The large variances in frequency of use in this study may be due to the wide range of sports, athlete levels, specific training modalities being developed, and coaches' education and experience with strongman implements.

The three main themes that emerged from coaches who did not use strongman implements in their athletes training were; a lack of equipment, there were more effective ways of training, and, strongman implement training was not specific to their sport. Additionally, over a third of coaches in this study reported that they had difficulty in acquiring strongman implements.

One disadvantage of using strongman implements with large groups of athletes is the inability to personalise load (Baker, 2008). Coaches used a variety of strategies to minimise this problem which included; monitoring volume and intensity, or pairing and grouping athletes. Using different sizes of equipment or equipment that was adjustable (i.e. kettlebells, sleds, farmers walk bars) was the main strategy used to overcome difficulties in individualising load.

Coaches reported other disadvantages of strongman implement training. The main disadvantage was the logistical demands of strongman implementation. This included; the cost of equipment, the setting up of equipment, weather; the lack of facilities; and, storage space. The perceived increased risk of injury associated with strongman training was another theme reported. While the majority of coaches (76%) believed strongman implement training carried the same risks as traditional training, researchers have reported that strongman implement training poses almost twice the risk of injury compared to traditional training approaches when equated for training exposure (Winwood, et al., 2014). Furthermore, the high lumbar loads experienced during strongman training could lead to injury (McGill, et al., 2009), especially if performed by athletes with insufficient training experience or if improperly progressed over time. Coaches should therefore endeavour to ensure that the competitive element among athletes is not overly emphasised, as this may see them overlook technique in the strongman lifts.

3.6 Conclusion

It seems that strongman implements are commonly used by the majority of coaches in their strength and conditioning practice. The authors acknowledge the limitation that the true prevalence of strongman use in strength and conditioning practice may not be as high as our numbers suggest, as coaches who use strongman implements may have been more likely to fill in the survey. However, the purpose of this study was to provide the first description of how strength and conditioning coaches are currently using strongman implements in non-strongman athletes' training programmes.

Coaches reported that strongman implements were useful tools for enhancing physiological and psychological performance factors in their athletes. Coaches used strongman implements both indoors and outdoors and in a variety of ways. Coaches reported that strongman implements were used to supplement traditional training programmes; however, the logistics of strongman implementation can be difficult. Strength and conditioning coaches can use the results of this survey as a review of strength and conditioning practices and as a possible source of new ideas to diversify and improve their training practices. Future research should investigate the chronic effects of strongman implement training on physiological and psychological performance parameters.

CHAPTER 4. THE RETROSPECTIVE INJURY EPIDEMIOLOGY OF STRONGMAN ATHLETES

4.1 Prelude

In recent years the sport of strongman has gained popularity with competitors performing functional movements in multiple planes under excessive loading. The movement patterns and loading associated with strongman events may place these athletes at high risk of injury. However, no peer-reviewed literature has examined the injury epidemiology of strongman athletes. Therefore, strongman athletes and strength and conditioning coaches have little evidence on the potential risks of incorporating strongman implement training into their training programmes. The first study presented in this thesis established how strongman implements are incorporated into coaches' strength and conditioning programmes, however, it did not establish the possible risks and injury potential of the inclusion of strongman implement training in their programmes. Therefore, the purpose of this second study was to gain some insight into the injury epidemiology associated with strongman training. It was thought that such an analysis would benefit strongman athletes as well as strength and conditioning coaches who include or wish to incorporate strongman implement training into their athlete's resistance training programmes.

Winwood, P. W., Hume, P. A., & Cronin, J. B., & Keogh, J. W. L. (2014). Retrospective injury epidemiology of strongman athletes. *Journal of Strength and Conditioning Research, 28*(1), 28-42

4.2 Introduction

The sport of strongman is similar to the sports of weightlifting, bodybuilding and power-lifting in which weight training is the primary form of exercise. In the late 1970’s and 1980’s, strongman athletes primarily trained as power-lifters or weightlifters and incorporated some bodybuilding training principles. Modern-day strongmen are hybrid athletes that combine a variety of traditional resistance training with sport-specific implement training (Winwood, et al., 2011). Since the sports inception in 1977, the sport of strongman has grown in popularity in many countries, both as a spectator sport and in terms of active competitors. Strongman competitions are hosted at local, regional, national and international levels and have divisions based on age, body mass, gender and experience.

Figure 4.1: Illustration of strongman events: A) stone lift; B) yoke walk; C) tyre flip: D) farmer’s walk; E) axle deadlift; F) log press. Photo’s reprinted with permission from *American Strongman Corporation.*

Some strongman events like the axle deadlift or log press are similar to those in weightlifting and power-lifting competitions where the athlete attempts to lift the heaviest load possible for one repetition or perform as many repetitions with the given load in a predetermined time limit. Other events such as the tyre flip, farmer's walk and yoke walk (see Figure 4.1) are timed with the winner being the fastest athlete to complete the required distance. Movement patterns used in strongman events require the strongman-specific implements to be carried/held for longer periods, and through different ranges of joint motions, than the bars used for power-lifting and weightlifting events. Like weightlifters and power-lifters, strongman athletes exert maximum effort to beat their previous personal records and other competitors and as such may be placing themselves at relatively high risk of injury.

Injury epidemiology of power-lifting (Brown & Kimball, 1983; Keogh, et al., 2006; Raske & Norlin, 2002), weightlifting (Calhoon & Fry, 1999; Raske & Norlin, 2002; Ren, et al., 2000) and bodybuilding (Eberhardt, et al., 2007; Goertzen, et al., 1989) provides critical information about injury prevalence and rates and some insight into causation. No injury epidemiology study has been undertaken with strongman athletes; only one case study (George, 2010) of a 38-year-old right-hand-dominant strongman competitor. The athlete sustained a simultaneous acute supraspinatus tear and a distal biceps rupture while attempting a 300 lb (~135 kg) overhead axle press. While acute rotator cuff tear is commonly associated with tearing of the proximal biceps tendon (Singaraju, et al., 2008), such an injury has not been reported in the literature to occur simultaneously with a distal biceps tendon rupture. Although only a case study, this injury may demonstrate that strongman athletes may be prone to potentially serious acute injuries that are not seen commonly during other physical activities.

Injury epidemiology knowledge would benefit strongman athletes as well as strength and conditioning coaches who wish to incorporate strongman event training into their athletes training programmes by providing the first empirical data on potential injury risk of strongman activities. The purpose of this study was therefore to provide the first empirical evidence of strongman training and competition injury epidemiology, with analyses by age, body mass and competitive standard.

4.3 Methods

4.3.1 Experimental Approach to the Problem

An online survey was used to provide retrospective descriptive epidemiology information about injuries associated with strongman implement training with analysis by age, body mass and competitive standard. The procedures used were based on those recommended for sports injury epidemiology research (Caine, Harmer, & Schiff, 2009). While retrospective designs has some limitations for injury epidemiology research due to injury recall (Gabbe, Finch, Bennell, & Wajswelner, 2003; Kolt & Kirkby, 1999), it appears that such issues are less problematic in athletes in the weight training sports who routinely keep training diaries (Winwood, et al., 2011). The use of a retrospective design is also warranted here as no strongman injury epidemiology studies have yet to be published and of the 12 injury epidemiology studies published in power-lifting, weightlifting and bodybuilding 11 have used the retrospective approach (Keogh, 2010b).

This study was approved by the university ethics committee where the study was conducted. In order to meet ethical approval, all questions in the survey were answered on a voluntary basis. As a result, the number of strongman athletes responding to each question item varied. Participant response numbers are indicated in the results section.

4.3.2 Participant Recruitment and Inclusion Criteria

Strongmen athletes were recruited via multimedia methods similar to previously described procedures (Winwood, et al., 2011). The networking site ‘Facebook’ was the primary method used to recruit the strongman athletes. Identified strongman athletes were sent a letter via email. The letter contained an invitation to participate in the research and the link to the online survey. Presidents of strongman clubs in New Zealand, Australia, USA and the United Kingdom were contacted to email the survey to their club members. An information sheet outlining the objectives and purpose of the study was situated on the first page of the online survey. Participants were asked to indicate their consent by participating in the survey. Surveygizmo.com was used to launch the electronic survey on the internet.

Participant inclusion criteria were male strongman athletes who used a training diary and had at least twelve months current experience in using common strongman exercises like the tyre flip, farmer's walk, and log press in their conditioning programmes. Four hundred and eight participants accessed the online survey, which included those that observed the survey, partially completed the survey and the 213 that fully completed the survey. The criterion for a completed survey was that the participant completed the first two sections of the questionnaire on personal details and resistance training experience, and at least one injury in the "previous injury" section if the athlete stated an injury had occurred.

4.3.3 Participant Characteristics

Two hundred and thirteen male strongman athletes from 19 countries completed the survey. Of the 213 strongman athletes, 175 athletes reported a previous injury had occurred and completed the previous injury section of the survey. The strongman athletes were (mean ±SD) 31.7 ±8.8 y, 181.3 ±7.4 cm, 113.0 ±20.3 kg, and had 12.8 ±8.1 y general resistance training experience and 4.4 ±3.4 y strongman implement training experience. Note: Nine female strongman athletes also completed the survey however due to their small subject number the data was omitted from this study. These results are presented in Appendix 6.

4.3.4 Research Instrument

Strongman athletes completed a self-reported 4-page 1-year retrospective *Injury Epidemiology of Strongman Athletes* survey created for this study based on a survey used with power-lifters (Keogh, et al., 2006). The original strongman survey was pilot tested with three university professors and then three strongman athletes to ensure its ease of use with strongman athletes. As a result of pilot testing, the survey was slightly modified including clarifying wording of some questions before being submitted online.

The survey requested information on personal details (age, height, body mass, resistance training experience and strongman training experience), resistance training characteristics (strongman implement use, and training duration and frequency), previous injury and injury risk factors. Participants were requested to detail their common/typical values for each question.

The injury section included questions on the nature of injuries (body site, type, onset, severity, first time or repeated occurrence) received in both training and competition. The exercise and load as a percentage of one repetition maximum (%1RM) resulting in injury and treatment type were ascertained. Injury was defined as any “physical damage to the body that caused the strongman athlete to miss or modify one or more training sessions or miss a competition” (Brown & Kimball, 1983; Keogh, et al., 2006; Raske & Norlin, 2002). Injured body sites were categorised as shoulder, neck, upper back, elbow, hip/buttock, knee, groin, chest, lower back, triceps, quadriceps, bicep, hamstrings or other. Injury types were categorised as bruise, laceration/cut, muscle strain/tear, tendon strain/tear, ligament sprain/tear, cartilage damage, bone fracture/break or other. Injury occurrence was categorised as first-time or repeated. Classifications of injury onset (i.e. acute/sudden or chronic), severity of injury and treatment and rehabilitation options were defined according to previously established methods (Keogh, et al., 2006). A moderate injury stopped the strongman athletes from performing an exercise while a major injury stopped their training completely.

The time of injury in relation to the training phase (e.g. general preparation) and in the training session or competition (i.e. early, middle or late) was ascertained. Injury-causing activities (events) were categorised as strongman implement training, traditional training, both strongman implement training and traditional training, or unknown. Strongman implement exercises were defined as exercises using any non-traditional training implements (e.g. stones, tyres, etc.). Traditional exercises were standard exercises performed in the gym by regular weight trainers and strength athletes (e.g. squat, bench press, etc.).

4.3.5 Statistical Analyses

Means and standard deviations were calculated for the participant characteristics and injury rates. Frequencies of responses were collated for questions related to the injury epidemiology of strongman athletes. Categorical and ordinal data were reported as both absolute numbers and percentage of responses. Scores for ranked questions were determined by weighted calculation in SurveyGizmo; items that were ranked first scored higher than the following ranks, so that the total score was the sum of all weighted ranks. Weighted calculations were based on the number of options represented. For example, the highest weighted score corresponded to the most dangerous strongman event. Injury rates were quantified according to previously established methods (Keogh, et al., 2006; Raske & Norlin, 2002) and were calculated for all participants, as well as the various subgroups of age (≤30 y and >30 y), body mass (lightweight <105 kg and heavyweight ≥105 kg) and competitive standard (high-level and low-level). Masters' classes such as those seen in power-lifting are not generally seen in the sport of strongman; therefore the age groups were chosen post-hoc to allow for a similar sample size for group comparisons. A body mass of 105 kg was used to separate the athletes as the two most common bodyweight classes in strongman competition are ≤105 kg and 105 kg (Open competition category). High-level strongman athletes were defined as those who had competed at a national or international competition, or performed professionally.

A 2-tailed unequal variance *t*-test was used to determine if any statistical differences ($p \leq 0.05$) existed in the demographics, training data and injury rate of the strongman athletes as a function of age, body mass and competitive standard. Differences among the subgroups regarding injury onset, injury severity, injury occurrence and treatment type were analysed with a Chi-square test. All analyses were performed using Microsoft excel (version 9.0; Microsoft, Seattle, WA).

4.4 Results

4.4.1 Demographics and Training Characteristics

Table 4.1 details the demographics and training characteristics for all 213 strongman athletes. Strongman athletes with significantly more strongman implement training experience had a higher competitive standard and were in the heavier body mass competition class. Although there was an average of 12.8 y of resistance training experience, only a third of those years included strongman implement training experience. In addition, weekly training using strongman implements accounted for a third of total resistance training time.

4.4.2 Exposure Time to Event and Exercise

Strongman athlete's ranked presses, lifts, carries/walks as the three most commonly used strongman movement categories in their training programmes. The tyre flip, yoke walk and stone lift were ranked as the three most dangerous exercises (see Figure 4.2).

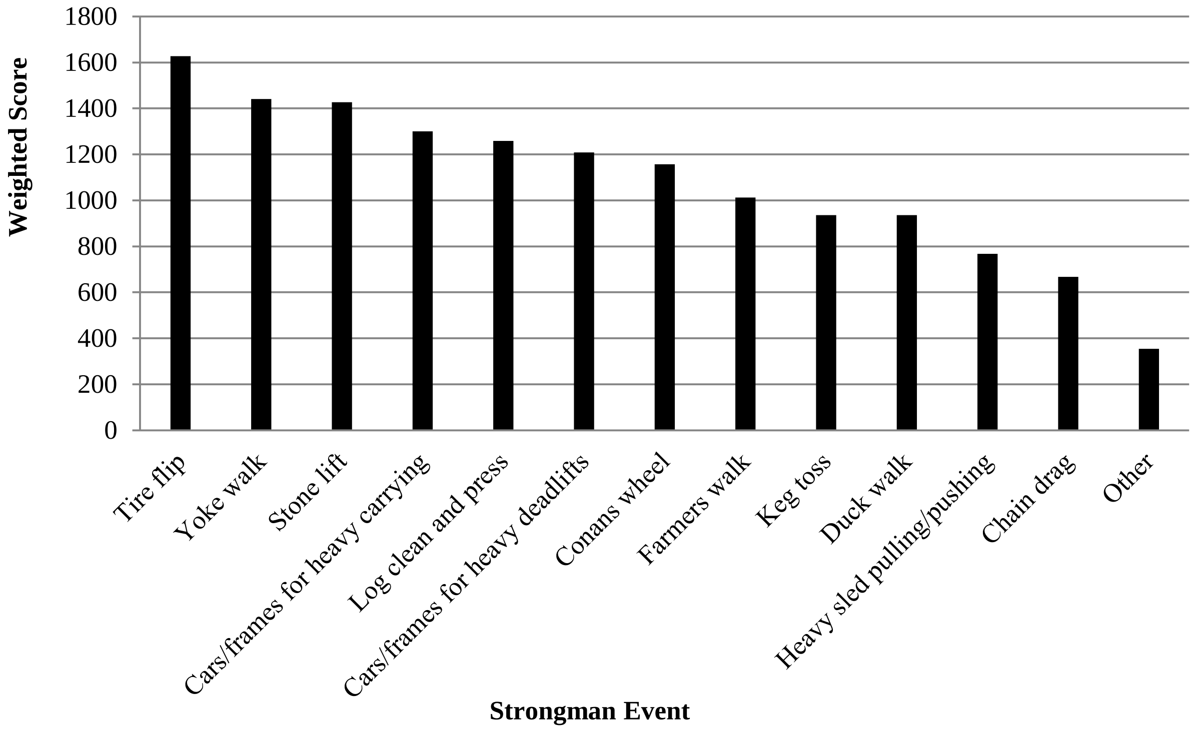

Figure 4.2: Strongman competition and training exercises ranked by strongman athletes (n = 213) from most dangerous to least dangerous.

Table 4.1: Demographics and training characteristics (mean ±SD) for strongman athletes.

		Age		Body mass class		Competitive standard	
	All Strongman athletes (n = 213)	≤30 y (n = 110)	>30 y (n = 102)	≤105 kg (n = 93)	>105 kg (n = 115)	Low-level (n = 115)	High-level (n = 98)
Demographics							
Age (y)	31.7 ±8.8	24.9 ±3.7	38.9 ±6.8†	30.6 ±9.5	32.4 ±8.4	31.4 ±8.2	31.9 ±8.9
Height (cm)	181.3 ±7.4	181.4 ±7.4	181.4 ±7.6	178.4 ±7.2	183.5 ±7.0†	180.6 ±7.8	182.1 ±7.0
Body mass (kg)	113.0 ±20.3	110.1 ±19.4	116.4 ±23.9	94.8 ±9.9	128.0 ±17.0†	109.5 ±21.5	117.4 ±21.5†$^{0.009}$
Training							
Resistance training experience (y)	12.8 ±8.1	8.2 ±4.2	17.8 ±8.4†	12.2 ±8.1	13.6 ±8.8	11.6 ±8.0	14.5 ±8.8†$^{0.013}$
Strongman implement training experience (y)	4.4 ±3.4	2.9 ±1.9	5.9 ±3.9†	3.7 ±2.9	5.0 ±3.6†$^{0.004}$	3.5 ±2.8	5.4 ±3.7†
Amount of strongman implement training (hr/wk)	2.0 ±1.6	2.0 ±1.5	1.9 ±1.7	2.0 ±1.7	2.0 ±1.6	1.7 ±1.4	2.3 ±1.7†$^{0.003}$
Amount of total resistance training (hr/wk)	6.5 ±3.1	6.8 ±2.9	6.1 ±3.3	6.1 ±3.2	6.8 ±3.0	6.0 ±3.1	7.0 ±3.0†$^{0.010}$

†significantly different to other level of variable p = <0.001 unless specified.

4.4.3 Injury Rate, Onset, Severity and Treatment

Table 4.2 provides the injury rates, onset, severity and treatment for injuries to the 174 injured athletes from the total 213 strongman athletes surveyed. Eighty two percent of strongman athletes sustained an injury in training and/or competition in the previous year; 76% received at least one training injury, while 31% had at least one competition injury. Sub-group analysis revealed only two significant differences in injury rates for strongman athletes injured in competitions. There were significantly more injuries per athlete per year for athletes ≤30 y than >30 y (0.5 ±0.8 vs 0.3 ±0.6; $p = 0.03$) and >105 kg than ≤105 kg (0.5 ±0.8 vs 0.3 ±0.6; $p = 0.014$).

Over two-thirds of injuries for the strongman athletes were acute, with 56% of all injuries having occurred for the first time. Nearly half the injuries were considered to be of moderate severity. Three groups (>30 y, ≤105 kg and high-level athletes) reported one quarter of their injuries were major. Strongman athletes utilised self-treatment (54%) or requested the assistance of medical professionals (41%) for their injuries. From sub-group analyses of the injured athletes, significant differences in the severity of injuries between the ≤30 y and >30 y, ($\chi^2 = 9.3$; df = 2; $p = 0.009$), and between the ≤105 kg and >105 kg ($\chi^2 = 6.1$; df = 2; $p = 0.046$) athletes were observed. Sub-group analyses of the injured athletes revealed significant differences in the treatment of injuries between the ≤30 y and >30 y ($\chi^2 = 6.3$; df = 2; $p = 0.043$) and low-level and high-level competition standard ($\chi^2 = 7.1$; df = 2; $p = 0.029$).

Table 4.2: The number (and percentage) of total occurrences for injury rate, onset, occurrence, severity and treatment reported by injured strongman athletes (n = 174).

Injury variable	All injured athletes (n = 174)	Age (n=173)		Body mass class (n=171)		Competitive standard (n=174)	
		≤30 y (n = 91)	>30 y (n = 82)	≤105 kg (n = 71)	>105 kg (n = 100)	Low-level (n = 92)	High-level (n = 82)
Rate							
Training injuries/athlete/y	1.6 ±1.5	1.6 ±1.5	1.5 ±1.4	1.6 ±1.7	1.6 ±1.3	1.4 ±1.6	1.5 ±1.3
Competition injuries/athlete/y (n=156)	0.4 ±0.7	0.5 ±0.8	0.3 ±0.6†$^{0.030}$	0.3 ±0.6	0.5 ±0.8†$^{0.014}$	0.3 ±0.6	0.5 ±0.7
Training injuries/1,000 hr	5.5 ±6.5	5.5 ±7.1	5.4 ±5.9	6.1 ±7.8	4.5 ±8.2	5.4 ±6.5	4.9 ±6.5
Onset							
Acute onset	176 (68)	83 (65)	93 (72)	68 (68)	105 (68)	91 (68)	84 (69)
Chronic onset	82 (31)	45 (35)	36 (28)	32 (32)	49 (32)	45 (33)	37 (31)
Occurrence							
First time	145 (56)	72 (55)	61 (55)	64 (62)	79 (52)	73 (54)	69 (57)
Repeated	115 (44)	58 (45)	51 (46)	39 (38)	74 (48)	62 (46)	53 (43)
Severity							
Mild	85 (33)	53 (41)	32 (25)	19 (21)	54 (35)	44 (32)	38 (31)
Moderate	123 (47)	58 (45)	64 (50)	49 (53)	73 (47)	70 (51)	53 (43)
Major	53 (20)	19 (15)	33 (26)	24 (26)	28 (18)	24 (17)	31 (25)
Treatment							
None	12 (5)	9 (7)	3 (3)	6 (6)	6 (4)	8 (6)	5 (4)
Self	141 (54)	76 (59)	53 (49)	57 (56)	81 (53)	84 (61)	56 (46)
Medical	106 (41)	43 (34)	52 (48)	38 (38)	66 (43)	46 (33)	60 (50)

Note: Discrepancies appear in age, body mass and competitive standard participant numbers when data were not reported by injured strongman athletes.

4.4.4 Injury Nature (Body Site and Type)

The lower back, shoulder, biceps and knee accounted for over 65% of all injuries (see Table 4.3). Muscle or tendon strains and tears were sustained in 60% of cases.

4.4.5 Exercises and Injury Sites

From the strongman athletes' injury data, traditional exercises accounted for just over half of injuries (deadlift 18%, squat 16%, overhead press 9%, bench press 6% and other 6%) (see Table 4.4). Strongman events accounted for 46% of injuries (9% stone work, 8% yoke walk, 6% tyre flip, 5% farmer's walk, 4% axle work, 4% log lift and press, 2% circus dumbbell and 8% other). Injury sites were similar for the traditional exercises and strongman events (lower back 15% and 8% respectively; shoulder 11% and 10%; knee both 5%), however strongman events were also associated with 9% bicep injuries. Note: A detailed table of strongman athletes' injury data is presented in Table A-5 (appendices).

From the rated perceptions of the 174 injured strongman athletes, 36% believed traditional exercises to be the direct cause of their injury, while 25% attributed their injury directly to strongman implement training. Thirty-five percent believed their injuries originated from both strongman implement and traditional training, while 4% were unsure of the causative activity.

Table 4.3: The number (and percentage) of total injury occurrences (n = 257) for body site and injury nature for the combined forms of resistance training reported by 174 injured strongman athletes.

Injury site	Bruise	Muscle strain/tear	Tendon strain/tear	Ligament sprain/tear	Cartilage damage	Bone fracture/ break	Other	Unsure	Total
Lower back		25 (9.7)	3 (1.2)	3 (1.2)	4 (1.6)	1 (0.4)	12 (4.7)	14 (5.4)	62 (24.1)
Shoulder		16 (6.2)	13 (5.1)	3 (1.2)		1 (0.4)	3 (1.2)	18 (7.0)	54 (21.0)
Bicep		9 (3.5)	17 (6.6)	1 (0.4)			1 (0.4)		28 (10.9)
Knee		2 (0.8)	8 (3.1)	6 (2.3)	5 (1.9)	1 (0.4)	2 (0.8)	4 (1.6)	28 (10.9)
Elbow		3 (1.2)	9 (3.5)	2 (0.8)				1 (0.4)	15 (5.8)
Upper back	1 (0.4)	6 (2.3)		2 (0.8)			2 (0.8)	2 (0.8)	13 (5.1)
Hamstring		11 (4.3)	2 (0.8)						13 (5.1)
Hip/buttock		5 (1.9)	1 (0.4)				4 (1.6)	1 (0.4)	11 (4.3)
Quadriceps		7 (2.7)					1 (0.4)	1 (0.4)	9 (3.5)
Groin	1 (0.4)	5 (1.9)	1 (0.4)	1 (0.4)					8 (3.1)
Chest		5 (1.9)	3 (1.2)						8 (3.1)
Neck		4 (1.6)	1 (0.4)				1 (0.4)		6 (2.3)
Ankle/foot						1 (0.4)			1 (0.4)
Wrist/hand	1 (0.4)								1 (0.4)
Total	3 (1.2)	98 (38.1)	58 (22.6)	18 (7.0)	9 (3.5)	4 (1.6)	26 (10.1)	41 (16.0)	257 (100)

Table 4.4: The number (and percentage) of injury sites (n = 268) by exercises for traditional and strongman events reported by injured strongman athletes (n = 174).

Event/ Exercises	Shoulder	Neck	Upper back	Elbow	Hip/butt	Knee	Groin	Chest	Lower back	Quads	Bicep	Hamstrings	Other	Total
Traditional	30 (11)	4 (2)	10 (4)	9 (3)	6 (2)	13 (5)	2 (1)	6 (2)	41 (15)	6 (2)	7 (3)	11 (4)		145 (54)
Deadlift		1	5	1	4	1	1	1	25	1	1	6		47(18)
Squats	4	1	1		2	11			12	5	3	3		42(16)
Overhead press	13	2	1	6					1		1			24(9)
Bench press	11							5						16(6)
Traditional other	2		3	2		1	1		3		2	2		16(6)
Strongman	26 (10)	2 (1)	6 (2)	6 (2)	4 (2)	13 (5)	4 (2)	2 (1)	22 (8)	3 (1)	23 (9)	3 (1)	9 (3)	123 (46)
Stone work	1		1			3	2		7		8		2	24(9)
Yoke walk	1	2	3		3	2			5	1	1		3	21(8)
Tyre flip	1			1		1			1	1	10		1	16(6)
Farmer’s walk	3		1	1		1	1		3	1		1		12(5)
Axle work	1			3	1	1	1		1		2		1	11(4)
Log lift/press	7					1		1	2					11(4)
Circus dumbbell	6													6 (2)
Strongman other	6		1	1		4		1	3		2	2	2	22(8)
Traditional and strongman total	56(21)	6(2)	16(6)	15(6)	10(4)	26(10)	6(2)	8(3)	63(24)	9(3)	30(11)	14(5)	9(3)	268(100)

Traditional other consists of glute ham raise (groin and hamstrings), ab wheel roll-out (upper and lower back), weighted chins and skull crushers (elbow), press ups and rotator work (shoulder), shrugs and rack pull (upper back), power clean and bent over row (bicep), hyperextension and good morning (lower back), leg press (knee). Strongman other consists of car dead lifts (shoulder, elbow, lower back), sled work and truck pull (knee, hamstrings and other), keg/barrel loading (knee and bicep), sandbags (shoulder and upper back), weight over bar/distance (shoulder and chest), kettle bell carry and wrestling (shoulder), frame carry (lower back), power stairs (hamstrings), duck walk (other), and palms up for hold (bicep). Stone work consists of stone lifts and carries. Axle work consists of presses and deadlifts.

The greatest injury frequency counts from the 174 injured strongman athletes were for the traditional exercises - the deadlift and squat with lower back injuries (37 injuries), and the overhead press and bench press with shoulder injuries (24 injuries), and the squat with knee injuries (11 injuries). There were also high frequency counts for the strongman exercises - the log lift/press and circus dumbbell with shoulder injuries (13 injuries), the tyre flip and stone work with bicep injuries (18 injuries) and the stone work with lower back injuries (7 injuries).

Of the total resistance training performed by all 213 strongman athletes, 31% was strongman implement training. However, for the 174 strong man athletes who were injured, when analyses of injuries was conducted to account for exposure to training with traditional or strongman implements, 66% of total injuries resulted from strongman implement training compared to 34% from traditional training. This means that strongman athletes were 1.9 times more likely to sustain injury when performing strongman implement training as compared to traditional training. While 40% of all 213 strongman athletes believed that strongman training carried a greater risk of injury than traditional training, 52% believed the risks of injury were the same for both training approaches.

4.4.6 Risk Factors for Injury (Load, Time, Technique)

For the 174 injured strongman athletes, injured strongman athletes sustained 91% of all injuries with heavy loads (70 to 90% 1RM), with the highest injury occurrence at a load of 90% 1RM (19%). Muscle strains and tears (39%), lower back (31%), and deadlift (26%) were most frequent with a load of 90%1RM. Injury occurrence was similar with average training loads and competition loads (83% and 86%1RM respectively).

Just over half (51%) of training injuries occurred in the general preparation phase. The most common time for injury was “early” in the training session (36%) with shoulder (29%) and muscle strains and tears (33%) most common. The squat accounted for 24% of all the early occurring training session injuries. Of all reoccurring injuries, 57% occurred early in the training session. Forty-four percent of injuries occurred “late” in the competition with bicep (35%) and muscle strains and tears (35%) most common. The stone and deadlift work (car and axle) accounting for 55% of all the late occurring competition injuries.

Nearly a quarter of all strongman athletes believed poor technique was the cause of their injury (see Figure 4.3). Overtraining/overuse, lack of warm-up/staying warm, a pre-existing condition/wear and tear, fatigue or the load being too great contributed to 35% of all injuries.

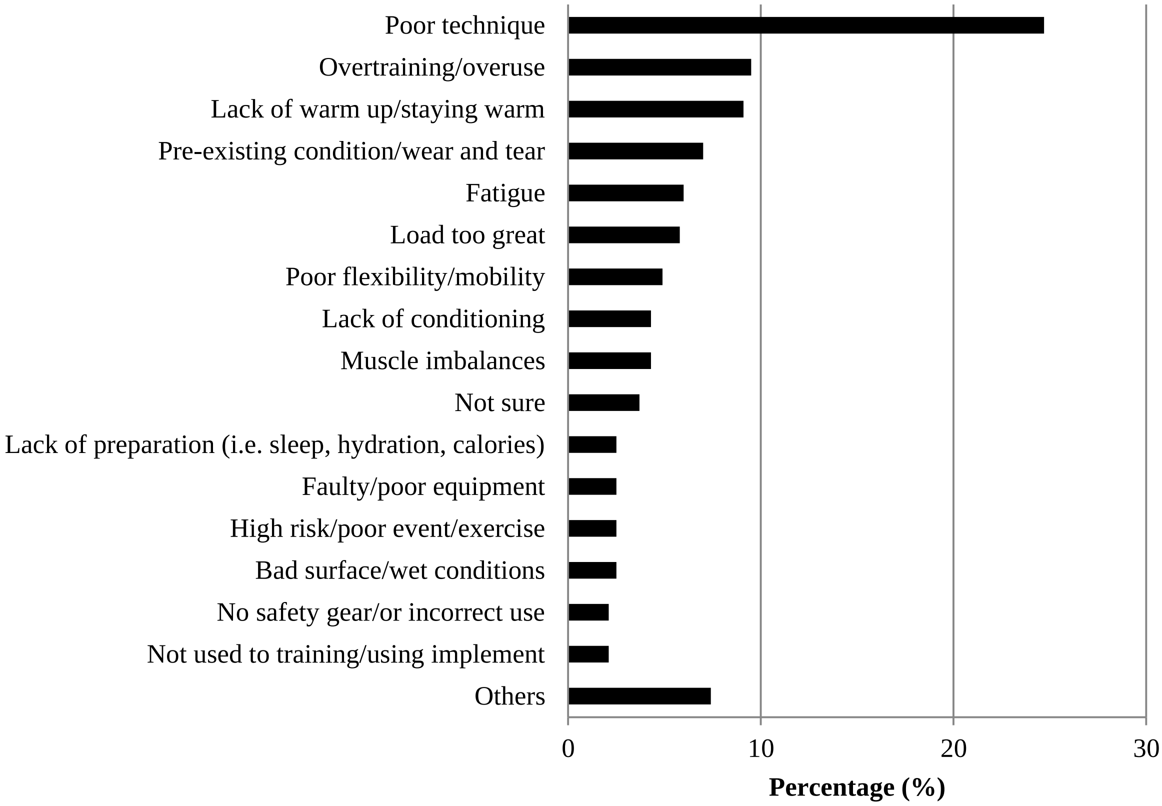

Figure 4.3: Risk factors reported by injured strongman athletes (n = 174) as being the cause of injuries (n = 243).

*In some cases, the strongman athlete provided information that represented more than one concept and their response contributed to more than one factor.

4.5 Discussion

The results of this exploratory retrospective study provide the first data on the injury epidemiology of strongman athletes. Only 20% of injuries in the current study were described as having a major effect (i.e. required a complete cessation of training for a week or more) which was similar to the 22% for power-lifters (Keogh, et al., 2006). However, strongman athletes suffered less mild (33%) and more moderate injuries (47%) than power-lifters (both 39%) (Keogh, et al., 2006). It seems that similar to power-lifters, injuries obtained by strongman athletes are not overly severe or disabling, requiring only minor or moderate modifications to the regular training programme.

In the current study the >30 y group had almost twice as many major injuries as the ≤30 y group. Morphological and mechanical changes in humans occur with age (Macaluso & Vito, 2004), which may be a reason for a greater rate of severe injuries in the older than young strongman athletes in the current study. However, such age-related differences were in contrast to results for Masters power-lifters (≥40 y) who had comparable injury severity to open aged power-lifters (Keogh, et al., 2006). Such results may therefore reflect sport-specific injuries in loading argued by Keogh (2010b) who found in a review a number of differences in the injury epidemiology of weightlifters, power-lifters and bodybuilders,

When the two training approaches were equated by exposure time, strongman implement training resulted in almost twice as many injuries as traditional training. Strongman athletes in this study ranked presses, lifts, and carries/walks as the three most commonly used strongman movement categories in their training programmes. In a recent study (Winwood, et al., 2011) strongman competitors (n =167) reported the farmer’s walk (96%), log press (95%), stones (94%), tyre flip (82%), axle work (80%) and yoke walk (75%) as the most common strongman implements used in their training programmes. These six events were listed the top six causative strongman exercises in current study, accounting for 77% of all injuries reported by strongman athletes. Based on the results of Winwood et al. (2011), such a result was expected as strongman exercises performed more commonly are likely to contribute to more injuries than exercises performed less frequently. The lack of any significant differences in the training injury rates for the strongman groups differentiated by age, body mass or competitive standard in this study was comparable to that found in power-lifting for the effect of age, body mass and gender but not for the effect of competitive standard (Keogh, et al., 2006). For further description of the training practices of strongman athletes, readers are referred to Winwood and colleagues (2011).

The 66% acute injuries for all the strongman athletes were slightly higher than the 59% acute injuries for power-lifters (Keogh, et al., 2006). However, such percentages must be interpreted with some caution as the present retrospective design and that of Keogh and colleagues (2006) lack medical confirmation. Some injuries may appear acute but could reflect chronic degeneration (Caine, Caine, & Lindner, 1996). In the present study, 44% of injuries were reported as being repeated injuries which may further suggest some chronic degeneration as a result of strongman training. Furthermore, strongman athletes may be participating in other physical activities that could potentially either result in injury or contribute to chronic maladaptations to increase the risk of injury during strongman training or competition.

An interesting finding in this study was the >105 kg group had proportionally less severe and moderate injuries than the ≤105 kg group. This was not expected as it was thought that this group would have more severe injuries due to the heavier loads these athletes train with and encounter in competition. Strongman competitions are generally divided into two body mass classes (≤105 kg and >105 kg) >105 kg class athletes generally lifting and/or carrying heavier loads than the ≤105 kg class. Thus, the strongman athletes in the >105 kg class are subjecting themselves to greater absolute musculoskeletal stresses than the ≤105 kg athletes, although such loads could be relatively lower relative loads given the greater cross sectional area of the loading structures. As there is a tolerance load of a certain magnitude in human tissue, increased mechanical loading on the musculoskeletal system can be an inciting factor for injury (Keogh, 2010b). Older strongmen may have more exposure to resistance and strongman training putting them at increased risk, conversely they have had a longer time to build up resistance over time, so could be at less risk. Research has demonstrated that world class power-lifters and world class strongman athletes can reduce spinal loading with greater loads than athletes with less experience (Cholewicki, et al., 1991; McGill, et al., 2009). Results from the current study and that of previous research (Cholewicki, et al., 1991; McGill, et al., 2009) most likely reinforce the importance of training technique and experience on stress reduction to the body and consequently injury reduction.

The lower back, shoulder, bicep and knee constitute the most commonly injured anatomical areas found in the strongmen. The most commonly injured sites from traditional exercises were, in descending order, the lower back, shoulder and knee, whereas for the strongman events this was the shoulder, bicep and lower back. These results pose the question as to what factors may contribute to these differences in the most commonly injured anatomical locations between traditional and strongman exercises.

Strongman events such as the yoke walk, farmer’s walk and tyre flip are total body movements performed in multiple planes that may involve periods of unilateral and bilateral ground contact and require the production of horizontal as well as vertical ground reaction forces. In contrast, traditional weight training movements used in bodybuilding power-lifting and weightlifting events are predominantly bilateral and vertical in nature, requiring the production of predominantly vertical ground reaction forces. As there are subtle-moderate differences in injury epidemiology of power-lifting, weightlifting and bodybuilding (Keogh, 2010b), it is likely that strongman training would also have somewhat unique injury risks and epidemiology due to the various types of exercises performed.

In power-lifting (which consists of the squat, deadlift and bench press) the most common sites of injury were shoulder, lower back, knee and elbow (Brown & Kimball, 1983; Keogh, et al., 2006; Raske & Norlin, 2002) whereas the most frequently injured sites in weightlifting (which consists of the snatch and clean and jerk) were the knee, shoulder, lower back, wrist/hand and elbow (Calhoon & Fry, 1999; Raske & Norlin, 2002; Ren, et al., 2000). In bodybuilding that uses weight-training equipment for training, but not competition, the sites of injury are varied depending on the study, however in a recent study the most frequently injured body sites were shoulder, wrist, arm/forearm, elbow joint and spine (Eberhardt, et al., 2007). The differences in the type and manner in which these exercises were performed in the various sports may explain the differences in injury epidemiology seen in the current study for traditional compared to strongman exercises (Keogh, 2010b).

The differences in injury sites between traditional training and strongman implement training may reflect the relatively unique stresses that some of these lifts/events place on the body (McGill, et al., 2009) Traditional exercises, (deadlift and squat) produce exceedingly large hip extensor torques (Brown & Abini, 1985; Cholewicki, et al., 1991; Escamilla, et al., 2000) and compressive or shear lumbar forces (Cholewicki, et al., 1991; Fortin & Falco, 1997). Winwood and colleagues (2011) reported that 100% of strongman competitors performed traditional exercises (i.e. squat and deadlift) as part of their training programmes; therefore the large percentage of lower back injuries with these exercises can be expected. We found that strongman athletes commonly incorporated the yoke walk and stone lift into their training programmes. The common use and stress associated with these events may increase the risk of injury. High spinal compression loads in the yoke walk have been attributed to the bracing action of the torso musculature to support the yoke load and to offset the deficiencies in hip abduction strength on weight acceptance with the swing leg (McGill, et al., 2009). Lower spinal compression loads associated with the stone lift compared to the yolk walk have been attributed to lifting technique (McGill, et al., 2009), as strongmen curve their torso over the stone, getting the stones' centre of mass close to their lower back. Stone lifting may still have quite high spinal injury risk as this technique increases the degree of spinal flexion angles and is associated with very high lower erector spinae activity (second highest after the tyre flip) (McGill, et al., 2009).

The shoulder is the most commonly injured anatomical region for power-lifters (Brown & Kimball, 1983; Keogh, et al., 2006) and bodybuilders (Eberhardt, et al., 2007). Many of these shoulder injuries could be attributed to the heavy loads used in upper body pressing exercises like the bench press and shoulder press. These traditional exercises and the strongman implements (axle, log and circus dumbbell press) produced the highest amount of shoulder injuries in the current study. The risk of shoulder injury may be reduced by performing overhead presses with the hands and elbows anterior to the shoulder with a neutral grip (Durall, et al., 2001; Ellenbecker, 2006), as seen in the strongman event the log press. However, reduced injury risk was not observed in this study, with loading parameters used with these exercises/events maybe a reason (Winwood, et al., 2011).

The incidence of biceps injury in the strongman athletes was higher than for weightlifting (Raske & Norlin, 2002), power-lifting (Keogh, et al., 2006; Raske & Norlin, 2002) and bodybuilding (Eberhardt, et al., 2007). Such results and basic kinesiology analysis of the events like the tyre flip and stone work suggest that bicep weakness or fatigue may limit the transfer of force produced from the larger muscle groups about the torso and shoulder and increase bicep injury risk.

Knee injuries accounted for 11% of all injuries which was similar to 9% for power-lifters (Keogh, et al., 2006) but lower than 19% for elite weightlifters (Calhoon & Fry, 1999). Strongman athletes attributed the squat to 42% of knee injuries. The similar percentages of knee injuries between strongman athletes and power-lifters may be due to the back squat being the most commonly performed squat by both groups (Winwood, et al., 2011). Weightlifters may be at greater risk of knee injury as exercises like front squats, clean and jerks and snatches produce greater torque at the knee due to the acute knee angle and/or larger anterior tibial translation (Fry, Smith, & Schilling, 2003; Keogh, 2010b). However, no injury was attributed to Olympic lifting by any strongman athlete in our study. Such a result is surprising as nearly 90% of strongman athletes perform Olympic lifts or their derivatives as part of their strongman training (Winwood, et al., 2011).

Muscle strains and tears (38%) and tendon strains and tears (23%) being common injuries for strongman athletes was also consistent with injury types for weightlifting (Calhoon & Fry, 1999; Singh & Kaur, 1999) and power-lifting (Brown & Kimball, 1983; Quinney, Warburton, Webster, Calvert, & Haykowsky, 1997). Acute bicep tendon injuries have been associated with bodybuilding and the snatch, and acute injuries to the quadriceps and patella tendons have been associated with the squat, clean, jerk and snatch (Lavallee & Balam, 2010). Tendon injuries are often the result of acute tensile overload and repetitive micro trauma as seen in overuse injuries (Lin, Cardenas, & Soslowsky, 2004).

To the authors knowledge only two other studies have investigated inciting events to injury in the weight-training sports (Eberhardt, et al., 2007; Ren, et al., 2000). In the present study 91% of all injuries to strongman athletes occurred with heavy loads (70 to 90% 1RM). Such a result suggests that injury and load may be highly correlated; however, no significant differences were found between loads (≤70% and ≥90%

1RM) and their effect on injury severity in this study. Injuries with these loads were consistent with the training and competition loads that characterised strongman training (Winwood, et al., 2011).

Injuries in bodybuilders (Eberhardt, et al., 2007) have occurred as a result of improper warm-up (42%), too vigorous exercising (35%) or a lack of “guarding assistance” (spotting) (7%). Interestingly, 36% of injured strongman athletes sustained training injuries that occurred early in the training session, a result which may further underscore the importance of adequate warm-up before heavy weight-training as performed in sports like strongman.

Technical errors are an important risk factor contributing to 31% of injuries in weightlifters (Ren, et al., 2000). Although strongman athletes cited poor technique (25%) as the most common contributing factor to injury, there appeared to be a greater variety of contributing factors.

Tiredness (fatigue) and excessive overload contributed to 81% of injuries for weightlifters (Ren, et al., 2000), a result considerably higher than the 13% for strongman athletes in our study. Fatigue can incite injury (Chappell, et al., 2005; Gabbett & Domrow, 2007) by altering motor control strategies and perhaps joint loading. Interestingly, 44% of the strongman athletes in our study sustained injury late in the strongman competition (as compared to 24% that occurred early or 33% that occurred in the middle of the competition), which may indicate fatigue and/or reduced concentration are contributing factors to competition injuries.

Forty-one percent of strongman athletes in our study consulted qualified health professionals for their injuries, which was higher than 25% for adolescent power-lifters (Brown & Kimball, 1983) but lower than 57% for power-lifters (Keogh, et al., 2006). Inter-study differences in injury management among power-lifters may be due to the differences in age, training experience and competitive standard (Keogh, et al., 2006).

While strongman may be considered dangerous due the extreme stresses these athletes place on their bodies, our surveyed strongman athletes suffered a relatively low injury rate (5.5 injuries/1,000 hr training) compared to national football league (NFL) athletes (12.7 injuries/1,000 athlete exposures to NFL practices) (Feeley, et al., 2008) but a relatively high rate than the other three weight training events of bodybuilding (1.0/1,000 hr training) (Eberhardt, et al., 2007), power-lifting (1 - 5/1,000 hr training) (Brown & Kimball, 1983; Keogh, et al., 2006; Raske & Norlin, 2002; Siewe, et al., 2011) and weightlifting (3 - 4/1,000 hr training) (Calhoon & Fry, 1999).

The present study sought to collect the full spectrum of epidemiologic data; particularly the variables missing from the current weight training literature (e.g. environmental location, onset, timing and nature of injury) (Keogh, 2010b). However, such in-depth analysis using a retrospective design can be problematic (e.g. high numbers of only partially completed questionnaires). Future research should involve the use of a prospective cohort or case-controlled design to minimise such limitations and examine the effect of a variety of independent variables on the injury epidemiology of this sport. Such designs could use a medical examination to increase the validity of the nature of the injury.

4.6 Practical Applications

Strongman athletes and strength and conditioning coaches who utilise these training methods should follow structured conditioning programmes with a periodised approach. Such an approach would help to ensure appropriate loading strategies for training phases and planned exercise progressions to ensure technical competency with these lifts/events. Supplemental training on areas vulnerable to injury with this mode of training may help reduce athletes' injury risk. Appropriate warm-up protocols and the avoidance of overtraining and fatigue may also play a part in reducing injury risk. Strongman athletes and strength and conditioning coaches can use these data as a possible source of new ideas to reduce their risk of injury and improve their training practices.

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CHAPTER 5. A BIOMECHANICAL ANALYSIS OF THE FARMERS WALK, AND COMPARISON WITH THE DEADLIFT AND UNLOADED GAIT

5.1 Prelude

Many strength and conditioning coaches are now utilising strongman implements in their athlete's strength and conditioning programmes. Understanding the kinematics and kinetics of exercises and the types of stress they impose on the body's system is a necessity for strength and conditioning coaches; as improvements in muscular performance occur as a result of acute and chronic adaptations to particular stresses. However, very little peer-reviewed literature has examined the kinematics and kinetics of any strongman events, with none of these studies directly comparing strongman and traditional lifts with the same sample of participants. Therefore athletes and strength and conditioning coaches have little understanding of the relative acute stresses that strongman training imposes on the body's system. The previous studies in this thesis established that strongman implements training are commonly used in strength and conditioning practice and carry almost twice the risk of injury than traditional resistance training exercises. Such findings reinforce the importance of better understanding the biomechanics of strongman events and how they may differ to traditional training approaches. The following chapters (Chapters 5 to 7) analyse the kinematics and kinetics of three strongman events; the farmers walk, heavy sled pull and log lift; and compare them with three commonly used traditional exercises (the deadlift, squat and clean and jerk) that appear to have some kinematic similarities. Such an analysis will allow for a more detailed understanding of strongman events, thus providing information for strength and conditioning coaches on the stresses that strongman training imposes on the body and the likely chronic adaptations to this form of training. In addition, the kinetic data presented on the strongman and traditional exercises will provide the necessary information to help accurately equate loading in the consequent training study presented in Chapter 8.

Winwood, P. W., Cronin, J. B., Brown, S. R. & Keogh, J. W. L. (In Press). A biomechanical analysis of the farmers walk, and comparison with the deadlift and unloaded walk. *International Journal of Sports Science & Coaching*.

5.2 Introduction

Strongman is a sport similar to weightlifting, bodybuilding and power-lifting in which weight training is the primary form of training (Winwood, et al., 2011). The farmers walk is a popular strongman event, used in training and in competitions, that requires athletes to pick up a heavy load (in a motion similar to the deadlift) in each hand and then walk a set distance, generally between 20 – 50 m as quickly as possible (Winwood, et al., 2011). The farmers walk would appear to require high anterior-posterior as well as vertical force production and may involve periods of unilateral and bilateral ground contact. In contrast, traditional weight training movements such as the deadlift are predominantly bilateral with the load being moved vertically. Corcoran and Bird (2009) have suggested that strongman type exercises such as the farmers walk are ideal exercises (as a supplement to traditional power training approaches) for transferring previously attained strength gains into more ‘functional strength’.

The farmers walk challenges the whole musculoskeletal system in terms of strength, stability, and physiological demands as it requires a very strong grip and core along with forceful triple extension of the ankle, knee and hip in the lifting and walking phases. The unique challenges associated with the farmers walk and its perceived benefits (improved total body and grip strength, gait loading pattern, trunk, knee, ankle and shoulder conditioning, dynamic core strength and stability and improved foot speed) may help explain its use as a conditioning method among strength and conditioning coaches (Corcoran & Bird, 2009; Poliquin & McDermott, 2005; Winwood, Cronin, Dudson, Gill, & Keogh, In Press-b). However a mechanical understanding of the farmers walk is limited.

Only two studies have examined the biomechanical (kinematic determinants of performance and lower back/hip loads) demands of the farmers walk (Keogh, et al., 2014; McGill, et al., 2009). McGill and colleagues (2009) examined trunk muscle activation and lumbar spine motion, load, and stiffness in three strongman competitors and made comparisons in the different strongman events e.g. the farmers walk, tyre flip, Atlas stones, log lift, and yoke walk. The walking events (i.e. farmers walk, yoke walk, left and right hand suitcase carry) were found to have greater activation of the abdominals (rectus abdominis, internal and external obliques), which occurred during the walking rather than lift phase, whereas the lower erector spinae peaked during the lift. McGill (2010) proposed that asymmetric carries such as unilateral farmers walk (referred to as the suitcase carry) would assist many athletes in training the torso brace and strength to support the hips, pelvis and spine.

Keogh and colleagues (2014) examined the kinematics of the farmers walk with five male strongman athletes who carried 90.5 kg in each hand for three trials of 20 m. Sagittal plane 2-D video analysis of the farmers walk showed velocity-dependent changes in kinematics similar to that seen in resisted (Keogh, et al., 2010b) and body weight sprinting (Hunter, et al., 2004), whereby significant increases in step length and step rate and decreases in contact time were observed when comparing the initial (0 – 3 m) to latter stages (8.5 – 11.5 m and 17 - 20 m). Significant differences were observed between stages at foot strike and toe off, with the initial stage (0 - 3 m) demonstrating greater ankle dorsiflexion, and greater knee and thigh flexion angles and smaller ranges of motion (ROM) than the latter stages. Interestingly, fewer significant kinematic differences were found between the fastest and slowest trials. Keogh et al. (2014) postulated that success in the farmers walk may be attributed to the ability to produce high levels of anterior-posterior propulsive impulses over short contact times. However, as the study of Keogh et al. (2014) was purely kinematic in nature, such an assertion requires kinetic data to be collected.

While Keogh et al. (2014) and McGill et al. (2009) provided some kinematic description and kinetic data of lower back/hip loads of the farmers walk, their choice of loads were somewhat arbitrary and neither reported the ground reaction forces for this event. Since the farmers walk is becoming more widely used by strength and conditioning coaches as a means of performance enhancement (Winwood, et al., In Press-b), it is important for coaches to have data on the kinematics and kinetics of this event to understand the potential stresses this event places on the body. Such data would give coaches a greater understanding of the acute stresses that the farmers walk imposes on the system and the likely chronic adaptations to this form of training.

The purpose of this study therefore, was to examine the kinetic and kinematic characteristics of the farmers walk (i.e. the lift and walk) and make comparisons with the conventional deadlift and unloaded walk. The conventional deadlift was chosen for comparison as this movement is the most commonly performed deadlift utilised by strongman athletes (Winwood, et al., 2011) and is comparable to the pick-up phase of the farmers walk. Such an analysis may also help equate loading and time under tension in future training studies wishing to compare the farmers walk versus the conventional deadlift exercise on aspects of muscular function and performance. Unloaded walking was chosen for comparison to help best show the differences between loaded and unloaded gait kinematics and kinetics. It was hypothesised that the kinematics and kinetics of picking up the farmers walk bars (called the farmers lift) would share many similarities with the conventional deadlift and that the walking phase of the farmers walk would be similar to unloaded walking but exhibit forces of greater magnitudes.

5.3 Methods

5.3.1 Experimental Approach to the Problem

A cross-sectional descriptive design was used to quantify and compare the kinematics and kinetics of the farmers walk, conventional deadlift and unloaded walk. The participants were well-trained strongman athletes with extensive experience performing the traditional and strongman lifts. Data were collected for each participant over two sessions separated by one week. Session one was performed in the strength and conditioning laboratory and involved 1-repetition maximum (1RM) testing in the deadlift. Session two was performed in the biomechanics laboratory where participants performed repetitions of the deadlift, unloaded walking and the farmers walk (respectively) on force plates using loads of the deadlift 70%1RM. Kinematics and kinetics were recorded during the second session.

5.3.2 Participants

Six male strongman athletes (four national and two regional level athletes) volunteered to participate in this study, a summary of the participant’s characteristics is presented in Table 5.1. All participants regularly performed 1RM testing as part of their training and had an extensive strength training background; including experience with the squat, deadlift, clean and jerk and strongman events including the farmers walk. The study was conducted two weeks before a regional strongman competition where the majority of athletes were at the end of a training cycle aimed at improving their previous competition performance. To be eligible to participate in this study the strongman athletes had to have at least 2-years of strongman training experience, competed in at least one strongman competition and be injury free. Prior to participation, all aspects of the research were verbally explained to each participant, written informed consent was obtained and a coded number was assigned to each participant to ensure the data remained anonymous. Full ethical approval for human subject research was granted for all procedures used in this study by the Auckland University of Technology Ethics Committee (12/311).

5.3.3 One-Repetition Maximum Testing

No supportive aids beyond the use of a weightlifting belt and chalk were permitted during the test. The warm up, loading increments and rest periods used were according to previously established protocols (Wilson, 1994). Maximum strength was assessed by a 1RM performed with a free-weight Olympic-style barbell. This form of strength assessment has been found to be highly reliable (ICC = 0.94) with resistance trained subjects (Ritti-Dias, Avelar, Salvador, & Cyrino, 2011). The alternate grip (cradle grip) was used by strongman athletes for 1RM deadlift testing. Completed lifts in the deadlift were recognised when the participants were standing still and fully upright with the applied load.

5.3.4 Deadlift and Farmers Walk Testing

Before performing the lifts, participants engaged in a self-selected total body dynamic warm-up similar to their specific weight training and competition warm-up procedures. Generally this began with two light sets of each lift (e.g., <40%1RM) for 6-10 repetitions. All the participants then performed testing loads of each exercise before any data collection. Loading for the farmers walk was the athletes' 70%1RM deadlift. Participants were asked to self-select their movement speed for the farmers walk and deadlift. For the farmers walk participants were instructed to pick up the bars in each hand and walk forward at their typical training pace. Before specific testing occurred, participant's unloaded walk data (at their typical walking speed) was also recorded for data comparison. Typical gait and farmers walk training pace speeds were analysed as these movements accurately depict the natural kinematics and kinetics of how these events are most commonly performed. Each participant performed two trials starting on the force plate and two trials starting 3 m behind the force plate. Participants were allocated a 2-minute rest period between trials. A longer rest period of up to 5-minutes was made available between trials if the athlete felt fatigued. Consistent verbal encouragement was provided during testing sessions. The participant's best lifts and farmer's walks (determined by the participant's) were used for analysis. The farmers bars (14.3 kg, length 1160 mm, handle thickness of 33 mm diameter) used in this study were purchased from Getstrength, Auckland. Shoes worn by participants during testing were those that were typically worn in their strongman training.

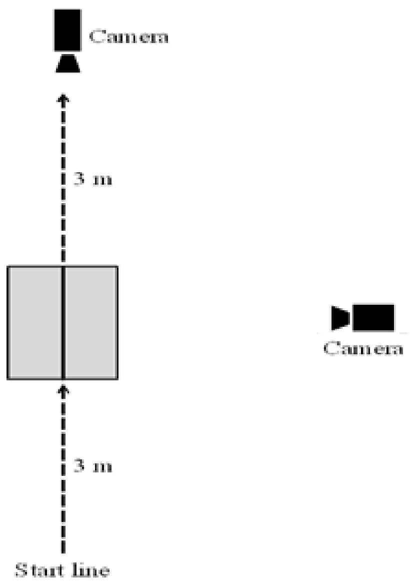

Figure 0.1: Sony camera and force platform set up.

5.3.5 Instrumentation

Twelve markers were bilaterally placed over the base of the third metatarsal, lateral malleoli, lateral femoral condyles, greater trochanter, anterior superior iliac spine and superior boarder of the acromion process. Two Sony HDR – CX 190E cameras (Tokyo, Japan) were used to track the coordinates of reflective markers adhered to the body, during the various trials at a sample rate of 60 Hz. A Bertec force plate (Model AM6501, Bertec Corp., Columbus, OH, USA) was used to collect synchronised ground reaction forces at 1000 Hz. A diagrammatic representation of the two cameras and force platform set-up is presented in Figure 5.1. Vicon Nexus (Version 1.8.1, Vicon Inc., Denver, CO, USA) was used to process the ground reaction force data. Ground reaction force data were filtered using a fourth order low-pass digital Butterworth filter with a cut-off frequency of 6 Hz.

Figure 0.2: Pictorial representation of the four angles measured in the 2-D analysis of the farmers walk. The top row from left to right depicts the ankle, knee, hip and trunk angles at foot strike and the bottom row at toe off.

<u>5.3.6 Data Analysis</u>

Two linear kinematic (average velocity and stride length), three temporal (stride rate, ground contact time and swing time) and four segment/joint angle (trunk, thigh, knee and ankle) variables were calculated. Gait angles were recorded at foot strike and toe-off (Figure 5.2) and lift angles were recorded at lift off (point at which load had left the ground), knees passing (point at which hands and bar/s passed the knees), and lift completion (maximal point of concentric lift) (Figure 5.3).

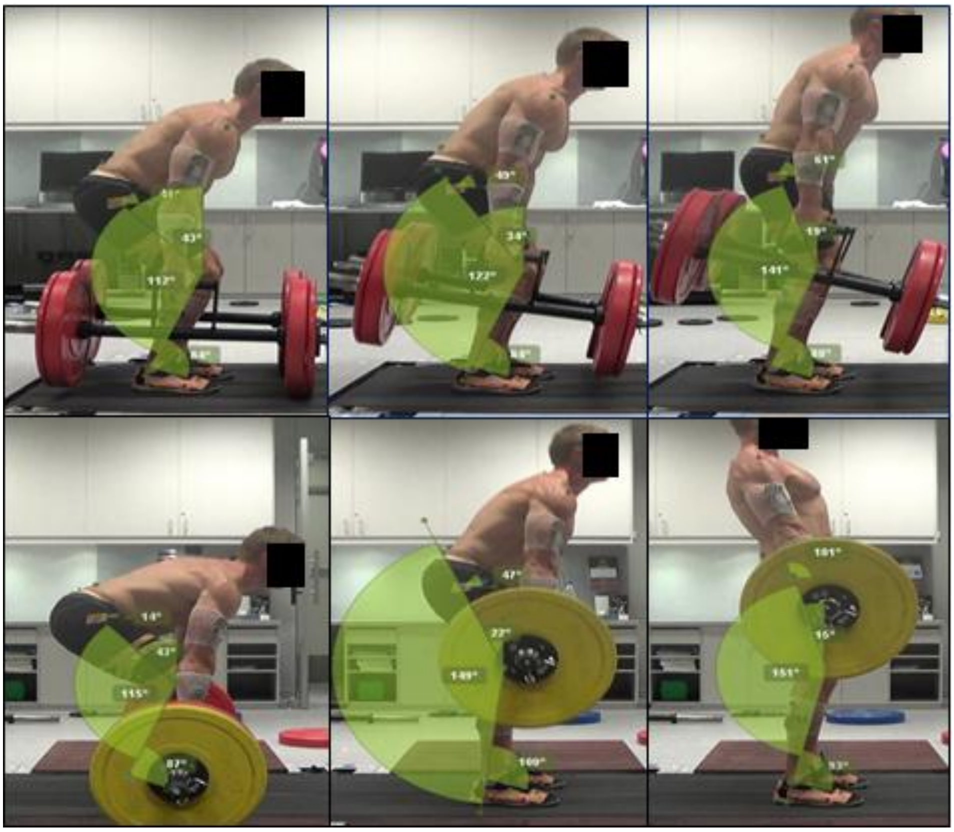

Figure 0.3: Pictorial representation of the four angles measured at LO, KP and LC (From left to right) in the farmers lift (top row) and deadlift (bottom row).

For the purposes of this study the farmers walk was analysed in 2 phases (i.e. farmers lift and farmers walk). The trunk and thigh angles were measured in absolute angles in relation to the horizontal and vertical axis (respectively) while the knee and ankle were relative (joint angles) (Keogh, et al., 2014). A general measure of the range of motion (ROM) of these joint/segments was obtained by subtracting the angle at toe off from that at foot strike, and lift off from lift completion. 2D kinematics for the trunk, thigh, knee and ankle angles were calculated for the right side and were analysed in Kinovea (version 0.8.15, www.kinovea.org) (intra-rater reliability ICC = 0.96-0.99 (Bowerman, Whatman, Harris, & Bradshaw, 2013)).

Linear kinematics and temporal values were analysed in Vicon Nexus. Force data was normalised for time using ensemble averaging in Microsoft Excel 2007 and presented as peak and mean values. Forces in the X and Y axis were calculated as medial (positive) and lateral (negative), and anterior (propulsive^{+}) and posterior (braking^{-}). Sum of mean forces in the X and Y axes were calculated as the total mean (e.g. X = medial + lateral forces). A definition for all the kinematic and temporal variables (adapted from Keogh et al. (2014)) is given below:

Average Velocity ($m.s^{-1}$): The total displacement of the movement divided by the time taken.
Stride length (m): Horizontal distance from heel strike of the first foot contact to the next heel strike contact of the same foot.
Stride rate (Hz): The number of strides per second.
Ground contact time (s): Time from heel strike to toe off of the same foot.
Swing time (s)*:* Time from toe off to heel strike of the same foot.
Trunk angle (°): The internal angle subtended from shoulder and hip to the horizontal axis, with larger values indicating greater trunk extension.
Thigh angle (°): The internal angle subtended from knee and hip to the vertical axis, with positive values indicating that the thigh was anterior to the hip.
Knee angle (°): The internal angle subtended from the hip, knee and ankle markers, with 180° indicating full knee extension.
Ankle angle (°): The internal angle subtended from the knee, ankle and toe, with increasing values indicating plantarflexion.

5.3.7 Statistical Analyses

Means and standard deviations were used as measures of centrality and spread of data. Two-tailed paired t-tests were used to determine if any statistical differences existed in kinematics and ground reaction forces between the farmers lift and deadlift, and the farmers walk and unloaded walk. Statistical significance was set at $p \leq 0.05$. All analyses were performed using IBM Statistical Package for the Social Sciences (Version 20.0, SPSS for Windows).

5.4 Results

Descriptive characteristics of all strongman athletes are presented in Table 5.1. On average strongman athletes trained four times a week for ninety minutes per session which totalled 6.4 hrs of strongman/resistance training per week.

Table 0.1: Demographics, training characteristics and strength measures (mean ± SD) for strongman athletes.

	All Strongman athletes (n = 6)
Demographics	
Age (y)	24.0 ± 3.9
Height (cm)	181.6 ± 9.4
Body mass (kg)	112.9 ± 28.9
Training	
Resistance training experience (y)	6.5 ± 2.7
Strongman implement training experience (y)	2.7 ± 1.6
Number of resistance training sessions per week	4.2 ± 1.2
Average time of resistance training sessions (min)	90.8 ± 30.4
Strength	
Deadlift 1RM (kg)	238.3 ± 22.3
Deadlift 1RM ($kg{\cdot}kg^{-1}$)	2.19 ± 0.39

5.4.1 Lifting Kinematics between the Farmers Lift and Deadlift

Participants demonstrated a greater stance width in the deadlift (38.9 ± 4.5 cm; $p = 0.0028$) compared to the farmers lift (26.3 ± 4.7 cm). Significant differences were observed in trunk angles between the deadlift and farmers lift, with the deadlift trunk angle being more horizontal at lift off (LO), and knees passing (KP) and more vertical at lift completion (LC) (see Table 5.2). The farmers walk and deadlift were found to differ significantly during KP for all angles, however, relatively few significant differences were observed for the ROM, LO and LC (Table 5.2).

Table 0.2: Kinematics of trunk, thigh, knee and ankle angles performed during the concentric lifting phase of the two exercises.

	Farmers Lift	Deadlift
Lift Off (LO)		
Trunk angle (^{0})	40.5 ± 4.1†	14.0 ± 5.7
Thigh angle (^{0})	47.3 ± 4.4	49.2 ± 9.0
Knee angle (^{0})	105.7 ± 4.0	110.0 ± 12.3
Ankle angle (^{0})	84.0 ± 5.9	88.8 ± 5.8
Knee Passing (KP)		
Trunk angle (^{0})	49.3 ± 6.2$^{†0.04}$	44.7 ± 3.4
Thigh angle (^{0})	39.8 ± 3.9†	25.2 ± 7.4
Knee angle (^{0})	114.0 ± 2.5†	144.8 ± 7.6
Ankle angle (^{0})	83.8 ± 5.3†	101.0 ± 5.0
Lift Completion (LC)		
Trunk angle (^{0})	73.5 ± 8.6$^{†0.005}$	99.8 ± 7.4
Thigh angle (^{0})	11.8 ± 6.3	14.7 ± 7.6
Knee angle (^{0})	150.5 ± 9.7	154.0 ± 9.6
Ankle angle (^{0})	90.2 ± 7.3$^{†0.04}$	97.7 ± 5.2
Range of Motion (ROM)		
Trunk angle (^{0})	33.0 ± 10.7†	85.8 ± 10.0
Thigh angle (^{0})	-35.5 ± 7.1	-34.0 ± 11.5
Knee angle (^{0})	44.8 ± 13.4	44.0 ± 17.5
Ankle angle (^{0})	6.2 ± 9.4	8.8 ± 8.0

Data expressed as mean ± SD.
†significantly different to other level of variable p = <0.001 unless specified.
Note: Smaller trunk, knee and ankle angles denote greater flexion. Smaller thigh angles denote greater extension.

5.4.2 Lifting Kinetics between the Farmers Lift and Deadlift

The farmers lift was found to have significantly higher mean vertical (2893 ± 442 N versus 2679 ± 471 N), mean anterior forces (66 ± 23 N versus 42 ± 15 N) and the sum of mean anterior-propulsive forces (38 ± 20 N versus 1 ± 4 N) compared to the deadlift (Table 5.3). While the lift times of the deadlift were significantly longer than the farmers lift (1.81 ± 0.24 s versus 0.92 ± 0.29 s), peak vertical velocity was significantly higher in the deadlift (0.76 ± 0.15 $m \cdot s^{-1}$ versus 0.44 ± 0.17 $m \cdot s^{-1}$), potentially due to the greater vertical displacement of the bar.

Table 0.3: Kinematics and kinetics of the deadlift and farmers lift.

	Deadlift	Farmers Lift
Z axis		
Peak Vertical Force (N)	3175 ± 494	3215 ± 508
Mean Vertical Force (N)	2679 ± 471$^{†0.021}$	2893 ± 442
Y axis		
Peak Anterior Force (N)	132 ± 62	184 ± 80
Mean Anterior Force (N)	41 ± 15$^{†0.007}$	66 ± 23
Peak Posterior Force (N)	-101 ± 34	-98 ± 38
Mean Posterior Force (N)	-39 ± 12	-36 ± 21
Mean of Y forces (N)	1 ± 4$^{†0.006}$	38 ± 20
X axis		
Peak Medial Force (N)	72 ± 19	67 ± 49
Mean Medial Force (N)	22 ± 9	19 ± 12
Peak Lateral Force (N)	-102 ± 55	-71 ± 29
Mean Lateral Force (N)	-23 ± 6	-21 ± 9
Mean of X forces (N)	-1 ± 6	-2 ± 20
Peak Vertical Velocity ($m \cdot s^{-1}$)	0.76 ± 0.15$^{†0.032}$	0.44 ± 0.17
Concentric Lift Time (s)	1.81 ± 0.24$^{†0.003}$	0.92 ± 0.29

Data expressed as mean ± SD.
†significantly different to other level of variable p = <0.001 unless specified.

Pictorial representations of group mean ground reaction force curves (normalised to percentage of mean lift time) for the deadlift and farmers lift are presented in Figure 5.4. Similarities can be observed in the shape of the force-time curves between the deadlift and farmers lifts in the lifting phases.

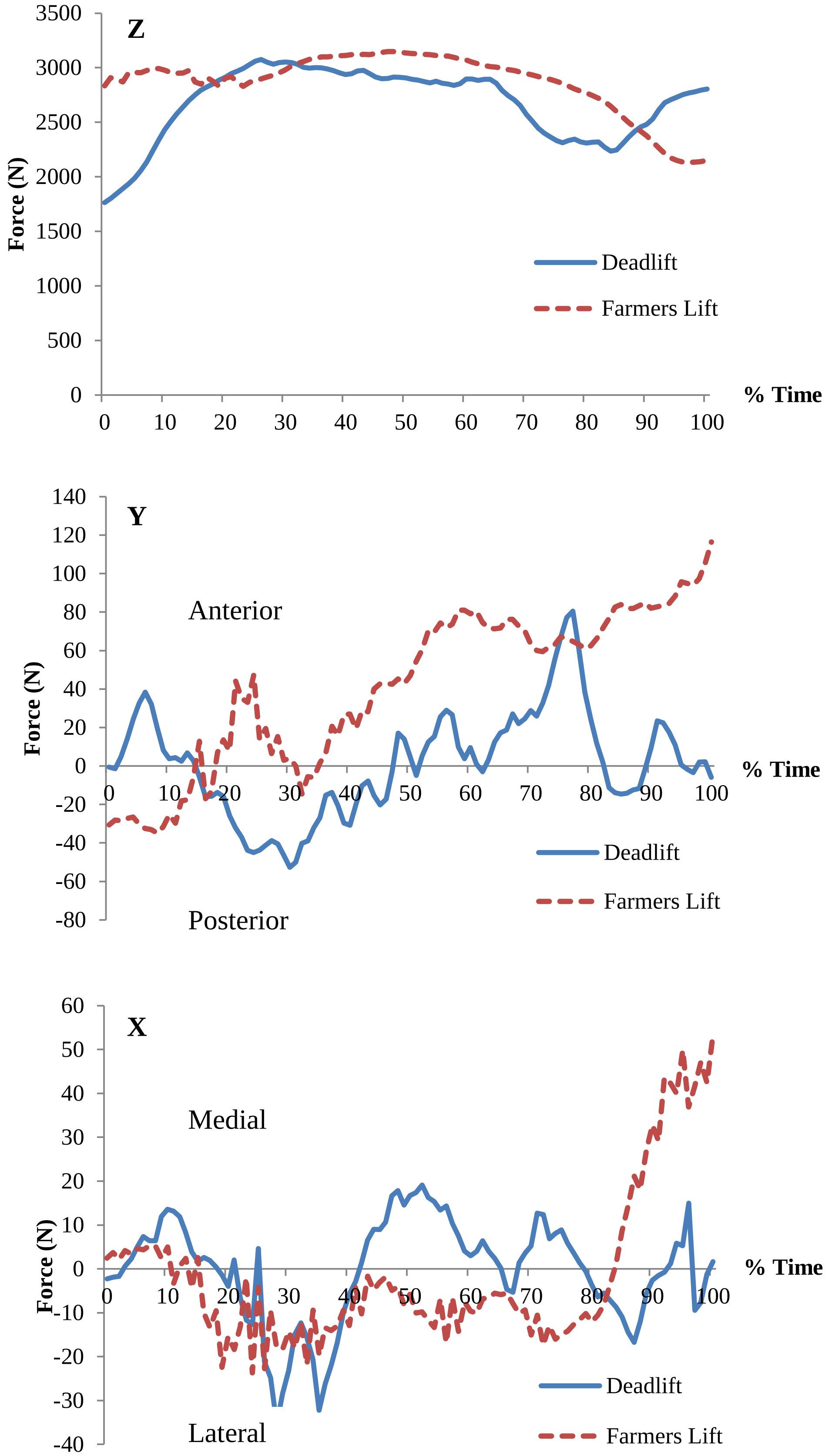

Figure 0.4: Group mean vertical (top), anterior/posterior (middle) and medial/lateral (bottom) force-time curves (normalised to percentage of mean lift time) obtained with a 70% 1RM load.

Table 5.4: Differences in gait kinematics between the farmers walk and unloaded walk

	Farmers Walk (1st Stride)	Unloaded Walk (1st Stride)	Farmers Walk (3 – 4 m)	Unloaded Walk (3 – 4 m)
Average velocity ($m{\cdot}s^{-1}$)	1.05 ± 0.21	1.11 ± 0.09	1.48 ± 0.19	1.26 ± 0.15
Stride length (m)	0.85 ± 0.19$^{\dagger 0.023}$	1.33 ± 0.11	1.04 ± 0.12$^{\dagger 0.002}$	1.43 ± 0.11
Stride rate (Hz)	1.21 ± 0.12†	0.82 ± 0.04	1.42 ± 0.17$^{\dagger 0.001}$	0.88 ± 0.06
Ground contact time (s)	0.53 ± 0.09$^{\dagger 0.002}$	0.77 ± 0.07	0.46 ± 0.06†	0.67 ± 0.06
Swing time (s)	0.24 ± 0.02†	0.44 ± 0.02	0.25 ± 0.02†	0.46 ± 0.03
Foot Strike (FS)				
Trunk angle (^{0})	68.5 ± 5.2$^{\dagger 0.016}$	85.3 ± 1.9	77.8 ± 3.3$^{\dagger 0.003}$	89.6 ± 2.4
Thigh angle (^{0})	26.0 ± 5.7	22.8 ± 6.5	33.8 ± 5.9$^{\dagger 0.05}$	22.8 ± 6.7
Knee angle (^{0})	150.0 ± 9.1$^{\dagger 0.033}$	174.0 ± 10.2	154.4 ± 6.5$^{\dagger 0.006}$	177.6 ± 6.0
Ankle angle (^{0})	95.8 ± 5.6$^{\dagger 0.033}$	105.3 ± 1.7	95.4 ± 2.7†	105.2 ± 2.4
Toe Off (TO)				
Trunk angle (^{0})	70.0 ± 4.7$^{\dagger 0.030}$	84.0 ± 3.5	75.8 ± 4.5$^{\dagger 0.002}$	87.2 ± 2.3
Thigh angle (^{0})	12.3 ± 12.1	7.8 ± 7.0	14.6 ± 9.5$^{\dagger 0.012}$	0.8 ± 6.1
Knee angle (^{0})	125.3 ± 10.1	121.3 ± 13.4	117.4 ± 11.1	126.6 ± 5.5
Ankle angle (^{0})	104.8 ± 6.3	117.5 ± 4.8	99.6 ± 5.4$^{\dagger 0.011}$	114.8 ± 8.7
Range of Motion (ROM)				
Trunk ROM (^{0})	1.5 ± 3.3$^{\dagger 0.049}$	-1.3 ± 2.6	-2.0 ± 2.9	-2.4 ± 1.9
Thigh ROM (^{0})	-13.8 ± 6.8	-15.0 ± 5.5	-19.2 ± 4.6	-22.0 ± 9.5
Knee ROM (^{0})	-24.8 ± 4.5$^{\dagger 0.013}$	-52.8 ± 9.7	-37.0 ± 8.6	-51.0 ± 8.4
Ankle ROM (^{0})	9.0 ± 9.5	12.3 ± 6.3	4.2 ± 4.3	9.6 ± 9.8

Data expressed as mean ± SD. †Significantly different to other level of variable $p<0.001$ unless specified. Note: Smaller trunk, knee and ankle angles denote greater flexion and plantar-flexion. Smaller thigh angles denote greater extension

5.4.3 Walking Kinematics between the Farmers Walk and Unloaded walk

Significant differences were found between the farmers walk and unloaded walk at 1st stride and at 3 – 4 m with the farmers demonstrating greater stride rates (48% and 61% greater), but lower stride lengths (36% and 27% less), ground contact times (both 31% less) and swing times (both 46% less) (respectively) (see Table 5.4). The farmers walk at 3 – 4 m demonstrated the greatest average velocity (1.48 ± 0.19 $m \cdot s^{-1}$). Significant kinematic differences were observed between the farmers walk and unloaded walk at foot strike (1st stride and 3 – 4 m) and toe off (at 3 – 4 m) for many joint and segment angles with the farmers walk demonstrating greater trunk flexion (69° and 78° versus 84° and 90°), knee flexion (154° and 117° versus 177° and 121°), and ankle dorsiflexion (95° and 105° versus 105° and 108°). A pictorial representation of the farmers walk and unloaded walk at heel strike and toe off is presented in Figure 5.5. Greater trunk flexion, reduced stride length and greater knee flexion at FS are clearly demonstrated in the farmers compared to unloaded walk.

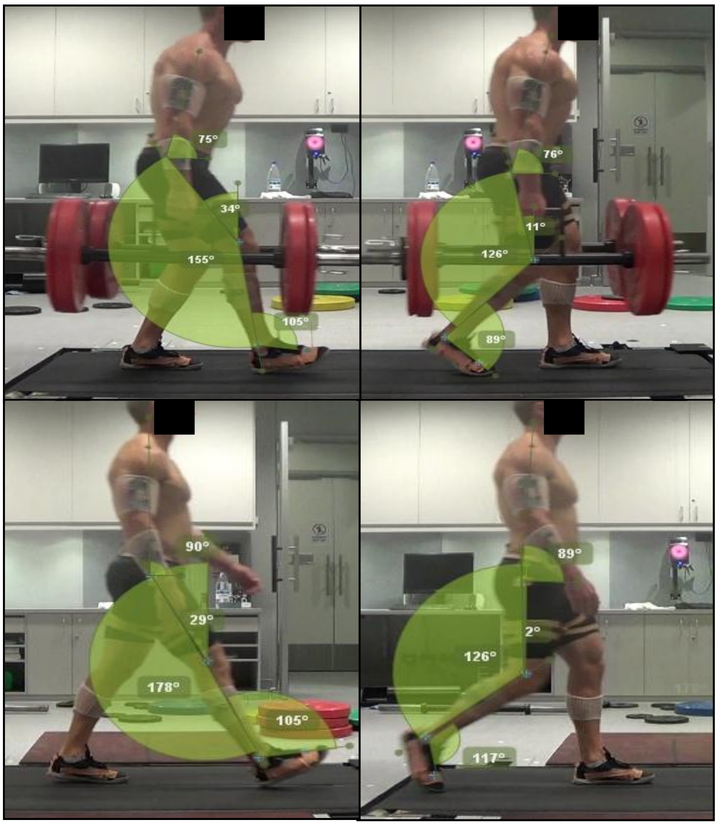

Figure 0.5: Pictorial representation of differences between the farmers walk and unloaded walk at heel strike (left) and toe off (right) at 3 – 4 m.

5.4.4 Walking Kinetics between the Farmers Walk and Unloaded Walk (3 – 4 m)

The farmers walk produced significantly greater peak and mean vertical (240% and 247% greater), peak and mean anterior (172% and 153% greater), peak and mean posterior (184% and 169% greater) and peak and mean medial (200% and 176% greater) and peak lateral forces (176% greater) than unloaded walk (respectively) (Table 5.5). Interestingly no significant differences were found in mean lateral forces between the loaded and unloaded conditions.

Table 0.5: Kinetics of unloaded walk and farmers walk (3 – 4 m).

	Unloaded Walk (1 stride at 3 – 4 m)	Farmers Walk (1 stride at 3 – 4 m)
Z axis		
Peak Vertical Force (N)	1510 ± 387†	3626 ± 608
Mean Vertical Force (N)	1025 ± 247†	2536 ± 376
Y axis		
Peak Anterior Force (N)	259 ± 53$^{†0.007}$	447 ± 98
Mean Anterior Force (N)	83 ± 25$^{†0.008}$	127 ± 31
Peak Posterior Force (N)	-211 ± 77$^{†0.017}$	-389 ± 143
Mean Posterior Force (N)	-94 ± 34$^{†0.003}$	-159 ± 45
Mean of Y forces (N)	-12 ± 12	-32 ± 40
X axis		
Peak Medial Force (N)	120 ± 62$^{†0.022}$	241 ± 73
Mean Medial Force (N)	70 ± 36$^{†0.042}$	120 ± 41
Peak Lateral Force (N)	-119 ± 45$^{†0.019}$	-210 ± 73
Mean Lateral Force (N)	-65 ± 29	-106 ± 31
Mean of X forces (N)	5 ± 11	13 ± 28

Data expressed as mean ± SD.
†significantly different to other level of variable p = <0.001 unless specified.

Group mean average force-time curves (normalised to percentage of mean lift time) obtained with unloaded walk and the farmers walk are presented in Figure 5.6. Although the shape of the force-time curves of the farmers walk and unloaded walk are similar, greater magnitudes of force are clearly observed in the farmers walk.

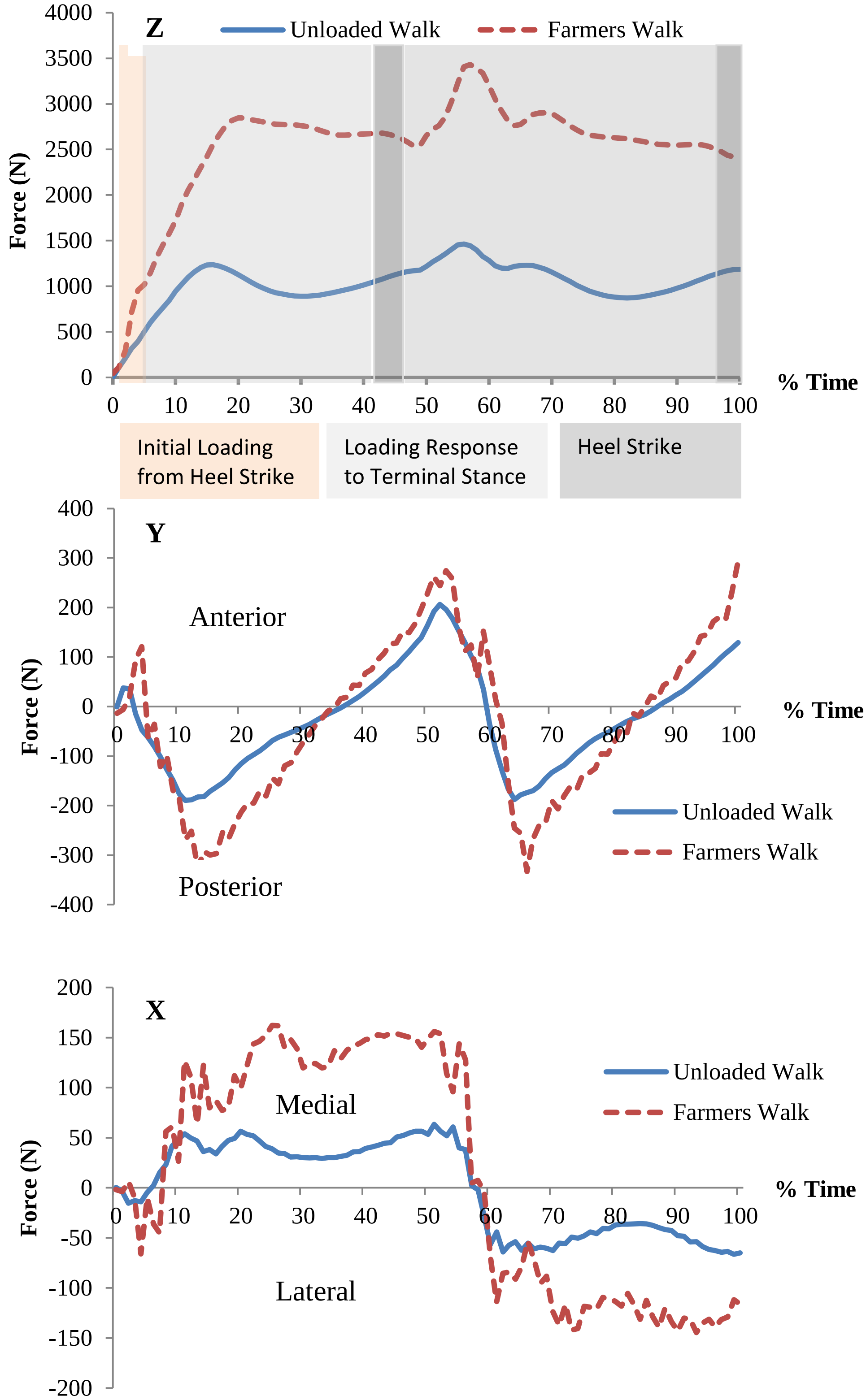

Figure 0.6: Group mean vertical (top), anterior/posterior (middle) and medial/lateral (bottom) average vertical force-time curves (normalised to percentage of mean lift time) obtained with unloaded walk at 3 – 4 m and the farmers walk with 70% 1RM load at 3 – 4 m. Graphs depict loading response from heel strike to heel strike for one stride (i.e. two steps).

5.5 Discussion

Since the farmers walk is becoming more widely used by coaches in strength and conditioning practice as a means of performance enhancement (Winwood, et al., In Press-b), the aim of this study was to gain a greater understanding of the acute stresses that the farmers walk imposes on the system and the likely chronic adaptations to this form of training. To achieve this, the kinetic and kinematic characteristics of the farmers walk (i.e. the lift and walk) were quantified and compared with the two comparable movements, the deadlift and unloaded walk. Significant kinematic and kinetic differences were observed between the lifting (i.e. the farmers lift and deadlift) and walking (farmers walk and unloaded walk) conditions. The peak vertical ground reaction forces of the deadlift and farmers lift (3175 ± 494 N and 3215 ± 508 N respectively) were comparable to those reported for power-lifters performing the hexbar deadlift and conventional deadlift with similar relative loads (70% 1RM) (Swinton, Stewart, Agouris, Keogh, & Lloyd, 2011). Significantly greater mean vertical force (2893 ± 442 N versus 2679 ± 471 N), mean anterior force (66 ± 23 N versus 42 ± 15 N) and sum of anterior-posterior forces (38 ± 20 N versus 1 ± 4 N) were observed in the farmers lift than the deadlift. The higher forces associated with the farmers lift are similar to the findings of Swinton et al. (2011) who found that lifts performed with the hexagon barbell deadlift produced consistently higher forces than the conventional deadlift with the same loads (20% to 80% 1RM). The greater mean forces in the farmers lift than deadlift may reflect the higher handle grips of the farmers bars and the associated significant kinematic differences. Specifically, the deadlift trunk angle was significantly more horizontal (65% less) at lift off and knees passing and significantly more vertical (36% greater) at lift completion compared to the farmers lift. The differences at lift completion reflect the hyperextension of the trunk associated with the end of the concentric phase of the deadlift (99.8 ± 7.4^{o}) whereas the angle at completion of the farmers lift (73.5 ± 8.6^{o}) reflected the need to take the first step of the farmers walk. Significantly greater ankle dorsiflexion, knee flexion, thigh extension and a more vertical trunk angle were found at knee passing for the farmers lift as opposed to the deadlift.

Deadlift kinematics in the present study, were similar to those reported for power-lifters (Escamilla, Lowry, Osbahr, & Speer, 2001) with stance width and relative knee and absolute trunk angles at lift off. Slight differences in knee and trunk angles were apparent at knee passing, which may be a result of the different loads used in these studies (e.g. 70%1RM vs 1RM) (Escamilla, et al., 2000; Swinton, et al., 2011). Interestingly, the kinematics of the farmers lift appears more similar to the sumo deadlift than the conventional deadlift. A three-dimensional biomechanical analysis of sumo and conventional style deadlifts (Escamilla, et al., 2000) found that, like the farmers lift, the sumo group maintained a more upright trunk and demonstrated greater hip and knee flexion at knees passing, whereas the conventional group positioned the shank closer to the vertical.

Swinton and colleagues (2011) found that deadlift performed with a hexagon barbell (also known as a trap bar) significantly reduced the moment arm at the lumbar spine, hip and ankle. The lifting kinematics and kinetics of the farmers lift may have some advantages over the conventional deadlift as an effective lifting alternative especially for athletes with a history of lower back pain or currently in the final stages of rehabilitation. Recent research on the injury epidemiology of strongman athletes (Winwood, et al., 2014) found that the deadlift was associated with the highest amount of lower back injuries among all traditional and strongman exercises performed by 174 strongman athletes. In contrast only three lower back injuries were associated with the farmers walk.

The present study sought to provide further insight into the farmers walk by providing kinematic and kinetic data of loaded carrying versus unloaded gait. Significantly shorter stride lengths', ground contact times and swing times and significantly higher stride rates, were associated with the farmers walk. Such results were expected as participants performed the farmers walk at 'training speed' which is faster than their preferred unloaded gait speed. Successful performance in the farmers walk is based on the fastest time to complete the event. Interestingly, the stride rate reported in this study (1.42 Hz) for the farmers walk (at 3 – 4 m) was higher than those reported (1.10 – 1.38 Hz) for running at 1.65 - 4.00 $m \cdot s^{-1}$(Luhtanen & Komi, 1973; Ōunpuu, 1994). It is quite likely that like sprinters (at higher speeds); strongman athletes increase their velocity by increasing their stride rate more than their stride length. Cooke et al. (1991) suggested that a shortening of stride length may be responsible for an improvement in economy with vertical loading as it may lead to a reduction in the vertical oscillation of the system's centre of mass.

The farmers walk (at 3 – 4 m) was found to have significantly greater dorsiflexion (95.4 ± 2.7 ^{o} vs 105.2 ± 2.4^{o}), knee flexion (154.4 ± 6.5^{o} vs 177.6 ± 6.0^{o}), thigh angle (33.8 ± 5.9^{o} vs 22.8 ± 6.7^{o}), and significantly lesser trunk angle (77.8 ± 3.3^{o} vs 89.6 ± 2.4^{o}) at foot strike than unloaded gait (at 3 – 4 m). Greater dorsiflexion at the ankle was attributed to a lesser stride length than unloaded walk and a more vertical shank segment angle. Collectively, these data indicate all three joints (ankle, knee and hip) are flexed more at foot strike in the farmers than unloaded walk. Such a strategy may help reduce braking forces and provide a more optimal position to generate propulsive forces from foot strike based on the muscles being at a more favourable length to take advantage of the length-tension relationship. Mean braking forces seen in the present study were only 41% greater in the farmers walk compared to unloaded walk, even though their system mass (body plus farmers bars) was close to 2.5 times their bodyweight.

Comparable flexion angles (^{o}) were seen in this study (at 3 – 4 m) in the thigh (34 ± 6^{o} vs 32 ± 3^{o}), knee (154 ± 7^{o} vs 150 ± 6^{o}) and ankle (95 ± 3^{o} vs 100 ± 8^{o}) at foot strike to that of Keogh and colleagues (2014) (at 0 – 3 m) in which five male athletes completed three 20 m farmers walk trials. Interestingly, average velocity (1.48 ± 0.17 $m \cdot s^{-1}$ vs 2.41 ± 0.32 $m \cdot s^{-1}$), stride length (1.05 ± 0.11 m vs 1.35 ± 0.12 m), stride rate (1.42 ± 0.17 Hz vs 1.79 ± 0.14 Hz), ground contact time (0.46 ± 0.06 s vs 0.36 ± 0.04 s), and swing time (0.25 ± 0.02 s vs 0.20 ± 0.02 s) in the present study were considerably less at 3 m than those reported by Keogh and colleagues (2014). Loading (70%1RM versus 90.5 kg) and environmental factors (laboratory versus outdoors course), coupled with the instructions for the participants to maintain 'good form at training pace' may explain the differences observed in this study.

Interestingly, the shape of the force-time profiles associated with the farmers walk were very similar to unloaded walk. A significant loading effect was however evident in ground reaction forces, with significantly greater peak and mean forces observed in all three axes during the farmers walk. The vertical forces in the farmers walk (with very heavy loads -70% 1RM deadlift), were similar to those reported for running (2.8 and 2.3 bodyweights at 4.5 $m \cdot s^{-1}$ and 5.0 $m \cdot s^{-1}$) (Cavanagh & Lafortu, 1980; Munro, Miller, & Fuglevand, 1987).

Peak anterior-propulsive forces and peak posterior braking forces were 1.72 and 1.84 times greater in the farmers walk than unloaded walk. Similar increases in horizontal force have been reported for sprint kinetics as running velocity increased from moderate to high maximum values (Brughelli, et al., 2011; Kyrolainen, Belli, & Komi, 2001). The results of this study support the contention of Keogh and colleagues (2014) that success in the farmers walk could be related to the ability to produce high levels of vertical and anterior-posterior propulsive impulses over short ground contact times. Studies are needed to investigate the effect of farmers walk velocity and load on anterior-posterior propulsive ground reaction force values.

The magnitudes of forces in the medial-lateral direction of the farmers walk and unloaded walk were comparatively smaller than those of the anterior-posterior or vertical components. An interesting finding in this study was that mean lateral forces although substantially greater in the farmers walk, were not significantly different to the unloaded walk. Large variances have been associated in the medial-lateral direction among individual runners (Cavanagh & Lafortu, 1980), which is similar to the findings of this study.

5.6 Conclusion

The results of this study provide coaches with the first biomechanical description of the farmers walk and provide insight into its kinetic and kinematic determinants. The farmers lift may have advantages over the conventional deadlift as an effective lifting alternative to generating more anterior-propulsive and vertical force with less apparent stress to the lumbar spine due to the more vertical trunk position. The farmers walk generated significantly higher vertical, anterior-propulsive and medial lateral forces in a characteristic gait pattern than unloaded walking. Such findings suggest that the farmers walk could prove to be an efficient mechanical stimulus to enhance various aspects of the gait cycle. Neuromuscular adaptations such as improvements in the production of anterior-propulsive forces, ankle strength and stability, lower body kinetic chain development, and core strength and stability may result from the inclusion of the farmers walk in resistance training programmes. However, longitudinal training studies are needed to validate such views.

CHAPTER 6. A BIOMECHANICAL ANALYSIS OF THE HEAVY SPRINT-STYLE SLED PULL AND COMPARISON WITH THE BACK SQUAT

6.1 Prelude

From Chapter 3 it was concluded that the heavy sled pull was the most commonly used strongman implement utilised in strength and conditioning practice. However, very little peer-reviewed literature has examined the kinematics and kinetics of the heavy sprint style sled pull and directly compared this exercise to a similar traditional exercise such as the back squat with the same sample of participants. The previous study provided athletes and practitioners with the first kinematic and kinetic description of the farmers walk. From the analysis it would seem that the farmers lift could be an effective lifting alternative to the deadlift and the walk could be an efficient mechanical stimulus to enhance various aspects of the gait cycle. The following chapter analyses the kinematics and kinetics of the heavy sprint style sled pull and makes comparison with the back squat. Such an analysis will allow for a more detailed understanding of heavy sprint style sled pull, thus providing information for strength and conditioning coaches of the stresses that heavy sled pull training imposes on the system and the likely chronic adaptations to this form of training. The kinetic data presented on the heavy sled pull and squat exercises will provide the pre-requisite information to help accurately equate loading between these exercises in the training study presented in Chapter 8.

Winwood, P. W., Cronin, J. B., Brown, S. R. & Keogh, J. W. L. (under 2nd review). A biomechanical analysis of the heavy sprint-style sled pull and comparison with the back squat. *International Journal of Sports Science & Coaching*.

6.2 Introduction

Strongman is a sport similar to weightlifting, bodybuilding and power-lifting in which weight training is the primary form of training. The heavy sprint-style sled pull is a strongman competition event (similar to the truck pull) in which participants wear a chest-mounted harness which is tethered to the weighted sled positioned behind the athlete. Successful performance in the heavy sprint-style sled pull event is based on the fastest times to complete the event. Recently, the heavy sprint-style sled pull has gained attention as a proposed form of training that may be beneficial for athletes whose sports require high levels of horizontal total momentum (i.e. body mass x velocity (kg ms^{-1})), such as track and field athletes and athletes of the rugby codes (i.e. rugby union, rugby league, and National Football League) (Baker & Newton, 2008; Jakalski, 1998; Keogh, et al., 2010b; Winwood, et al., In Press-b).

The use of resisted sprinting training methods (such as the heavy sprint-style sled pull) are believed to increase power and strength through more muscle fibre recruitment and neural activation which consequently lead to an increase in stride length (Alcaraz, Palao, & Elvira, 2009). Keogh and colleagues (2010b) found that the heavy sprint-style sled pull shared many kinematic similarities to acceleration phase of sprinting, although the sled pull had somewhat smaller step lengths and step rates, longer ground contact times and a more horizontal trunk. Six resistance-trained athletes performed three 25-m sets with a load of 171.2 kg with 3 minutes rest between sets. Within subject analyses demonstrated that the fastest trials were often characterised by significantly greater step lengths, step rates and shorter ground contact times than the slower trials. Keogh et al. (2010b) surmised that based on the impulse-momentum relationship, greater anteroposterior force/impulses were produced in the fastest sled pulls. Keogh and colleagues (2010b) hypothesised that the heavy sprint-style sled pull may help improve acceleration sprinting performance.

However, the view of Keogh et al. (2010b) is inconsistent with some other authors who believe that the acute alteration in sprint kinematics observed during resisted sprinting training will not facilitate the practice and refinement of the correct neuromuscular pattern that would occur in non-resisted sprinting (Lockie, et al., 2003; Rushall & Pyke, 2001). These authors' beliefs appear based on research demonstrating that athletes experience an acute decrement in resisted sprinting speed via a reduction of step length and step rate and increased ground contact time, with these effects becoming more pronounced as the loads exceed 20% body mass (Alcaraz, et al., 2008; Lockie, et al., 2003; Maulder, Bradshaw, & Keogh, 2006).

Inspection of resisted sprint training studies highlights that no heavy sprint-style sled pull training studies have utilised loads such as those used by Keogh et al. (2010b), however researchers have reported that loads of 13% body mass and sled weights of 33 kg are effective at significantly improving 5 m (Harrison & Bourke, 2009; Kawamori, Newton, Hori, & Nosaka, In Press) and 10 m sprint times (Kawamori, et al., In Press). Kawamori and colleagues (In Press) compared the effects of heavier and lighter weighted sled towing on sprint acceleration ability. The study found that after 8-weeks of training twice weekly, the heavier sled (33.1 ± 5.9 kg) training group significantly improved both 5- and 10-m sprint time (5.7 ± 5.7% and 5.0 ± 3.5%; $p < 0.05$), whereas only the 10-m sprint time was improved significantly by 3.0 ± 3.5% ($p < 0.05$) in the lighter sled (10.8 ± 2.3 kg) group. An interesting finding in the study of Kawamori et al. (In Press) was that sprint speed increased as a result of improvements in step frequency and may have been attributed to decreased vertical impulse production. Kawamori and colleagues (In Press) therefore hypothesised that weighted sled towing with heavier loads improves sprint acceleration performance by teaching athletes to produce larger horizontal or resultant GRF impulse.

While the studies of Keogh et al. (2010b) and Kawamori et al. (In Press) were both successful in obtaining some kinematic determinants of performance and training adaptations associated with heavier sled towing loads, there is a lack of knowledge of biomechanical characteristics (e.g. magnitude and direction of force application and kinematic differences between early and latter sled pull strides), associated with the heavy sprint-style sled pull as compared to traditional exercises such as the squat. Since heavy sled pulls are the most commonly used strongman-type implement used by coaches in strength and conditioning practice (Winwood, et al., In Press-b), it is important for coaches to have data on the kinematics and kinetics of this event to understand the potential stresses this event places on the body. Such data would give practitioners a greater understanding of the applications and likely chronic adaptations to this form of training. Therefore, the purpose of this study was to examine the kinetic and kinematic characteristics of the heavy sprint-style sled pull. The heavy sprint-style sled pull was analysed in three phases: 1) the initial start (bilateral start to maximum knee extension); 2) first stride; and 3) stride at 2 – 3 m. The stride pattern (phases 2 and 3) were analysed to help give insight into changes in kinematics, force application/direction and the influence of static versus sliding friction during early acceleration.

The start of the heavy sled pull (from the bilateral start of the concentric phase to the maximum point of knee extension) was analysed and compared with the squat, as the movement patterns between these two exercises are comparable during this phase. Such an analysis is analogous to a recently published paper by Winwood and colleagues (In Press-a) comparing a strongman event referred to as the farmers walk to a similar traditional exercise, the deadlift. The study compared similar phases of the farmers walk with traditional exercises, and analysed the farmers lift with the deadlift and the farmers walk with unloaded walk (In Press-a). These types of studies may also help equate loading and time under tension in future training studies wishing to compare exercises such as heavy sprint-style sled pull versus the squat on aspects of muscular function and performance. It was hypothesised that the mean ratio of forces would be higher in the heavy sled pull's first stride compared to the stride at 2 – 3 m and the start of the heavy sled pull (to maximum knee flexion) would show significantly greater anteroposterior and lower vertical forces compared to the squat.

6.3 Methods

6.3.1 Experimental Approach to the Problem

A cross-sectional descriptive design was used to quantify the kinematics and kinetics of heavy sprint-style sled pull and the squat. The participants were well-trained strongman athletes with extensive experience performing the traditional and strongman lifts. Data were collected for each participant over two sessions separated by one week. Session 1 was performed in the strength and conditioning laboratory and involved 1-repetition maximum (1RM) testing in the squat. Session 2 was performed in the biomechanics laboratory where participants performed repetitions in the squat and heavy sled pull (respectively) on force plates using loads equal to 70% of the squat 1RM load for both exercises. Kinematics and kinetics were recorded during the second session. The sled pull was analysed in three phases; 1) the initial start (bilateral start of the concentric phase to maximum knee extension); 2) first stride; and 3) stride at 2 – 3 m. Only the initial start of the heavy sled pull (where feet were together) was compared with the squat, given the biomechanical similarities between the two exercises in this phase.

6.3.2 Participants

Six male strongman athletes (four national and two local level athletes) volunteered to participate in this study (mean ± SD: age 24.0 ± 3.9 yrs; stature 181.6 ± 9.4 cm; body mass 112.9 ± 28.9 kg). A summary of the participants' descriptive statistics is presented in Table 6.1. All participants regularly performed 1RM testing as part of their training and had an extensive strength training background; including experience with the squat and heavy sprint-style sled pull. The study was conducted 2 weeks before a regional strongman competition where the majority of athletes were at the end of a training cycle aimed at improving their previous competition performance. To be eligible to participate in this study the strongman athletes had to have competed in at least one strongman competition and be injury free. Prior to participation, all aspects of the research were verbally explained to each athlete, written informed consent was obtained and a coded number was assigned to each athlete to ensure the data remained anonymous. Full ethical approval for human subject research was granted for all procedures used in this study by the Auckland University of Technology Ethics Committee (12/311).

6.3.3 One-Repetition Maximum Testing

No supportive aids beyond the use of a weightlifting belt were permitted during the test. The warm up, loading increments and rest periods used were according to previously established protocols (Wilson, 1994). Maximum strength was assessed by a 1RM performed with a free-weight Olympic-style barbell. This form of strength assessment has been found to be highly reliable (ICC = 0.94) with resistance trained subjects (Ritti-Dias, et al., 2011). Squat 1RM was assessed using the methods outlined by Baker (1999a). Participants performed the low-bar back squat (power-lifting squat) as this squat is typically utilised in training and competition by strongman athletes.

6.3.4 Squat and Sled Pull Testing

Before performing the lifts, participants engaged in a self-selected total body dynamic warm-up similar to their specific weight training and competition warm-up procedures. Generally this began with two light sets of each lift (e.g., <40%1RM) for 6-10 repetitions. All the participants then performed testing loads of each exercise before any data collection. Once suitably prepared, the participants performed a trial of the exercise to commence with a load of 70%1RM. Loading for the sled pull, was determined by the athletes' 70%1RM squat. Athletes' were asked to perform the squat and heavy sprint-style sled pull as explosively as possible.

For the heavy sprint-style sled pull participants were instructed to start in a four-point power position and accelerate the heavy sled forward over a linoleum-coated floor as quickly as possible using powerful triple extension of the lower body. Carpet was attached to the bottom of the sled so that it could be dragged across the linoleum floor surface without causing damage to the floor (see Figure 6.1). Each participant performed two trials starting on the force plates and two trials starting 1 m behind the force plates.

Figure 0.1: Carpet attached to the sled to prevent damage to the linoleum floor.

The lifts were performed in a non-randomised order involving the squat then the heavy sled pull. This order was necessary as the heavy sprint-style sled pull was deemed to be the most metabolic demanding exercise. Participants performed three consecutive squat repetitions and then performed two sled pull trials on the force plate and two sled pull trials from 2 m behind the force plate. The first starting position for the sled pull was chosen to obtain kinetic data of; a) the start of the movement (i.e. concentric phase) to maximum knee extension and b) the first stride of the sled pull where the athlete who starts on the force plate has to overcome static friction of the sled. The second starting position of 2 m behind the force plate was selected so to provide data on an early dynamic phase of the sled pull (stride at 2 – 3 m) in which the athlete has to overcome the sliding friction of the sled. Participants were allocated a rest period of 5-minutes between the sled pull trials. Consistent verbal encouragement was provided during testing sessions with the athletes' frequently reminded to perform the exercises as fast as possible. The participant's best squats and sled pulls (determined by the participants) were used for analysis. If participants identified no differences in technical proficiency between trials, the trial with the highest resultant force was used for analysis. The sled (Strongman pulling sled, 11.5 kg, length 600 mm, width 400 mm) used in this study were purchased from Getstrength (Auckland, New Zealand). Shoes worn by participants during testing were those that were typically worn in their strongman training.

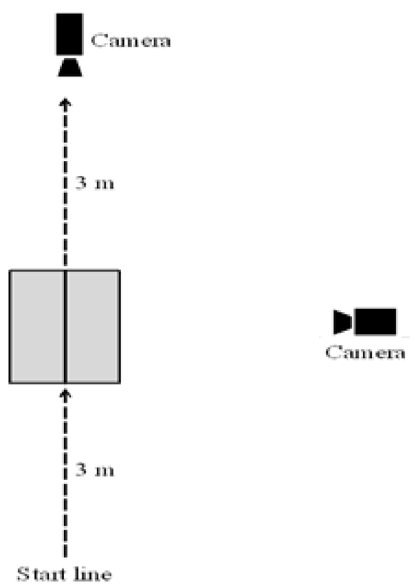

Figure 0.2: Sony camera and force platform set up.

6.3.5 Instrumentation

Twelve markers were bilaterally placed over the base of the third metatarsal, lateral malleoli, lateral femoral condyles, greater trochanter, anterior superior iliac spine, and superior boarder of the acromion process. Two Sony (HDR – CX 190E) cameras (Tokyo, Japan)) were used to track the coordinates of reflective markers, adhered to the body, during the various trials at a sample rate of 60 Hz. A Bertec force plate (Model AM6501, Bertec Corp., Columbus, OH, USA) was used to collect synchronised ground reaction forces at 1000 Hz. A diagrammatic representation of the 2 cameras and force platform set-up is presented in Figure 6.2. Vicon Nexus (Version 1.8.1, Vicon Inc., Denver, CO, USA) was used to process the ground reaction force data. Ground reaction force data were filtered using a fourth order low-pass digital Butterworth filter with a cut-off frequency of 6 Hz.

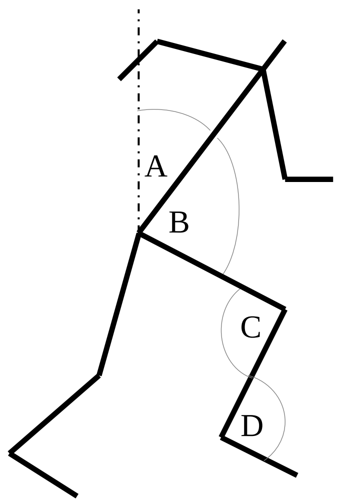

Figure 0.3: Schematic representation of the joint angles calculated (adapted from Keogh et al. 2010)

6.3.6 Data Analysis

Two linear kinematic (average velocity and stride length), three temporal (stride rate, ground contact time and swing time) and four segment/joint angle (trunk, hip, knee and ankle) variables were calculated. Squat and the sled pull start angles were recorded at the start of concentric phase (SC) (first frame before upward or forward movement, respectively), and at maximal knee extension - (MKE). These positions were chosen as they were similar positions that could be compared between the two exercises. Sled pull stride angles were recorded at foot strike (first point of ground contact) and toe-off (first point of foot leaving the ground). For the purposes of this study, sled pull strides were analysed in positions (i.e. first stride and stride at 2 - 3 m). The internal hip (B), knee (C) and ankle (D) angles (joint angles) were measured along with the trunk angle (A) in relation to the vertical axis (see Figure 6.3). A general measure of the range of motion (ROM) of these joint/segments was obtained by subtracting the angle at toe off from that at foot strike, and start of concentric phase from maximal knee flexion. 2D kinematics for the trunk, hip, knee and ankle angles were calculated for the right side and were analysed in Kinovea (version 0.8.15, www.kinovea.org) (intra-rater reliability ICC = 0.96-0.99 (Bowerman, et al., 2013)). Linear kinematics and temporal values were analysed in Vicon Nexus. Force data was normalised for time using ensemble averaging in Microsoft Excel 2007 and presented as peak and mean values. Vertical forces were described as acting in the Z direction, with upwards directed forces being positive. Forces in the X and Y axis were calculated as medial (positive) and lateral (negative), and anterior (propulsive^{+}) and posterior (braking^{-}), respectively. Sum of mean forces in the X and Y axes were calculated as the total mean (e.g. X = medial + lateral forces). A definition for all the kinematic and temporal variables (adapted from Keogh et al. (2014)) is given below:

Average Velocity (m.s^{-1}): The total distance from the first foot contact to the next foot contact of the same foot divided by the time taken.
Stride length (m): Horizontal distance from the first foot contact to the next foot contact of the same foot.
Stride rate (Hz): The number of strides per second. Calculated as the inverse of the stride time, where stride time is from heel strike to heel strike of the same foot.
Ground contact time (s): Time from foot strike to toe off of the same foot.
Swing time (s)*:* Time from toe off to foot strike of the same foot.

The four joint angles analysed in this study (Figure 25) were defined as follows:

Trunk angle (A): The angle subtended from shoulder and hip to the vertical axis, with smaller values indicating greater trunk extension.
Hip angle (B): The internal angle subtended from the shoulder, hip and and knee markers, with increasing values indicating greater hip extension.

Knee angle (C): The internal angle subtended from the hip, knee and ankle markers, with 180° indicating full knee extension.

Ankle angle (D): The internal angle subtended from the knee, ankle and toe, with increasing values indicating plantar-flexion.

In addition to examining the magnitude of force application in all three axes, we also investigated the direction of force application by calculating the mean ratio of forces applied onto the ground (Kawamori, Newton, & Nosaka, 2014; Morin, Edouard, & Samozino, 2011). The ratio (%) was calculated as the mean ratio of horizontal force (Fh) to the total resultant force ($\sqrt{X^2+Y^2+Z^2}$) (Ftot). It was thought that reporting these variables would give coaches a better idea of how horizontally oriented the heavy sprint-style sled pull is, and allow indirect comparison relative to previous research on sprint acceleration, and lighter sled towing methods (Kawamori, et al., 2014; Morin, et al., 2011).

6.3.7 Statistical Analyses

Means and standard deviations were used as measures of centrality and spread of data. Two-tailed paired t-tests were used to determine if any statistical differences existed in kinematics and ground reaction forces between the squat and sled pull (from the start of position of the concentric phase to the maximum knee extension), and the two sled pull stride positions (for the first stride and the stride at 2 – 3 m). Statistical significance was set at $p \leq 0.05$. All analyses were performed using IBM Statistical Package for the Social Sciences (Version 20.0, SPSS for Windows).

6.4 Results

Descriptive characteristics of all strongman athletes are presented in Table 6.1. On average strongman athletes trained four times a week for ~90 minutes per session for a total of 6.4 hours of strongman/resistance training per week.

Table 0.1: Demographics, training characteristics and strength measures (mean ± SD) for strongman athletes.

	All Strongman athletes (n = 6)
Demographics	
Age (y)	24.0 ± 3.9
Height (cm)	181.6 ± 9.4
Body mass (kg)	112.9 ± 28.9
Training	
Resistance training experience (y)	6.5 ± 2.7
Strongman implement training experience (y)	2.7 ± 1.6
Number of resistance training sessions per week	4.2 ± 1.2
Average time of resistance training session (min)	90.8 ± 30.4
Strength (1RM)	
Squat (kg)	210.0 ± 59.1
Squat ($kg \cdot kg^{-1}$)	1.87 ± 0.28

6.4.1 Exercise Kinematics between the Squat and Heavy Sled Pull

Participants demonstrated a greater stance width in the squat (51.01 ± 9.98 cm; p = 0.049) compared to the start of the heavy sled pull (40.88 ± 9.76 cm). As expected, significant differences were observed in trunk angles between the squat and sled pull, with the sled pull trunk angle being significantly more horizontal at the start of concentric phase (SC) and at the end of the concentric phase (maximal knee extension - (MKE)) (see Table 6.2). The squat demonstrated significantly greater knee flexion at SC and greater knee and hip extension at MKE. Hip and knee range of motion (ROM) was greater in the squat (205% and 280%, respectively) compared to the sled pull.

Table 0.2: Kinematics of trunk, hip, knee and ankle angles performed from the start of the concentric phase to the end of the concentric phase (maximal knee extension) for the Squat and Sled pull (from a bilateral plate start).

	Squat (SC to MKE)	Sled pull (SC to MKE)
Start of Concentric Phase (SC)		
Trunk angle (°)	38.8 ± 5.2†	101.4 ± 5.7
Hip angle (°)	57.0 ± 9.7	65.6 ± 12.6
Knee angle (°)	62.6 ± 6.3†0.007	95.8 ± 18.5
Ankle angle (°)	81.0 ± 7.3	76.0 ± 7.3
Maximum knee Extension (MKE)		
Trunk angle (°)	10.0 ± 4.3†0.007	81.2 ± 20.0
Hip angle (°)	163.0 ± 5.5†0.006	117.4 ± 11.0
Knee angle (°)	167.4 ± 4.6†0.01	133.2 ± 10.1
Ankle angle (°)	105.0 ± 3.9	107.8 ± 7.2
Range of Motion (ROM)		
Trunk angle (°)	-28.8 ± 5.1	-20.2 ±19.7
Hip angle (°)	106.0 ± 9.3†0.002	51.8 ± 19.0
Knee angle (°)	104.8 ± 9.8†0.004	37.4 ± 14.7
Ankle angle (°)	24.0 ± 6.1	31.8 ± 9.4

Data expressed as mean ± SD.
†significantly different to other level of variable p = <0.001 unless specified.

6.4.2 Exercise Kinetics between the Squat and Heavy Sled Pull

The squat was found to have significantly higher peak and mean vertical forces (both 2 times greater) than the sled pull, whereas the sled pull had significantly higher peak (6 times greater) and mean anterior forces (13 times greater) (see Table 6.3) than the squat. The sum of Y forces was significantly ($p < 0.001$) greater in the sled pull compared to the squat. Significant differences ($p < 0.001$) in the mean ratio of forces were evident between the start of the heavy sled pull and the squat, with the squat demonstrating force in the vertical direction (RF = 0.2 ± 0.3 %) as opposed to the greater horizontal force orientation (RF = 39.3 ± 5.9 %) associated with the start of the heavy sled pull. Total lift time for one repetition of the squat (including eccentric and concentric phases) was 2.81 ± 0.50 s.

Table 0.3: External ground reaction forces of the squat and heavy sprint-style sled pull (from the bilateral start of the concentric phase (SC) to the point of maximal knee extension (MKE)).

	Squat (SC to MKE)	Heavy Sled Pull (SC to MKE)
Z axis		
Peak vertical force (N)	3503 ± 1268†0.005	1736 ± 463
Mean vertical force (N)	2579 ± 648†	1326 ± 364
Y axis		
Peak anterior force (N	126 ± 73†	810 ± 174
Mean anterior force (N)	43 ± 22†	555 ± 107
Peak posterior force (N)	-133 ± 79	-53 ± 48
Mean posterior force (N)	-35 ± 13	-32 ± 24
Mean of Y forces (Fh) (N)	-8 ± 10†	522 ± 110
X axis		
Peak medial force (N)	89 ± 44	156 ± 72
Mean medial force (N)	19 ± 9	72 ± 47
Peak lateral force (N)	-90 ± 55	-94 ± 57
Mean lateral force (N)	-23 ± 15	-53 ± 35
Mean of X forces (N)	-3 ± 8	3 ± 52
Total resultant ground reaction force (Ftot) (N)	2579 ± 649†	1440 ± 368
Mean ratio of forces applied onto the ground (%)	0.2 ± 0.3†	39.3 ± 5.9

Data expressed as mean ± SD.
†Significantly different to other level of variable $p < 0.001$ unless specified

Pictorial representations of group mean ground reaction force curves (normalised to percentage of mean lift time) for the squat and heavy sprint-style sled pull from SC to MKE are presented in Figure 6.4. Differences in the shapes of the force time curves in the Z and Y axis are clearly evident; however some similarities can be observed in the X axis.

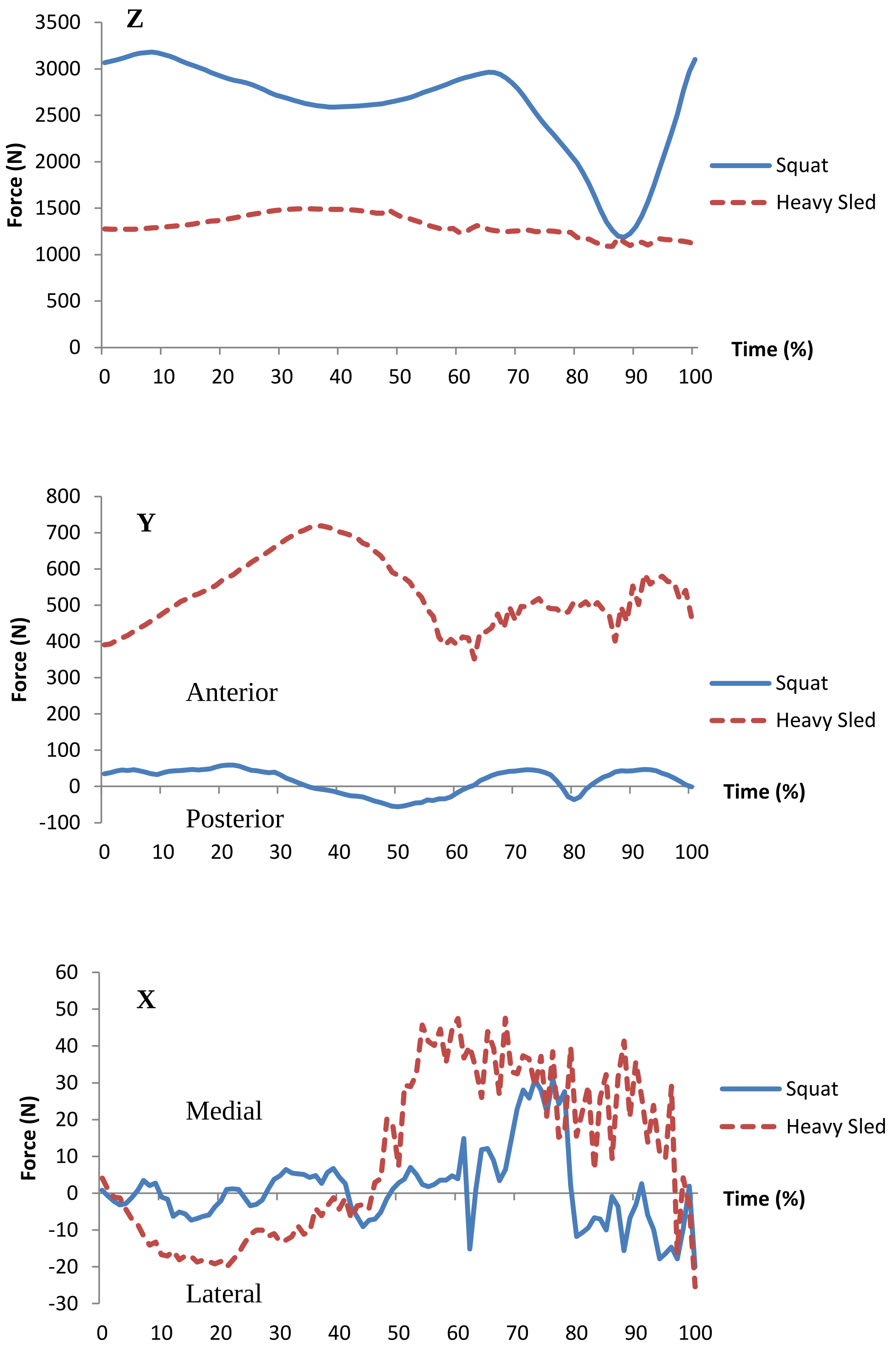

Figure 0.4: Group mean vertical (top), anterior/posterior (middle) and medial/lateral (bottom) force-time curves (normalised to percentage of mean lift time) obtained with a 70% 1RM load for the squat and heavy sled pull (from the start of the concentric phase to the end of the concentric phase (maximal knee extension).

6.4.3 Exercise Kinematics between Heavy Sled Pull Strides

Significant differences were found between the heavy sled pull first stride and stride at 2 - 3 m with the first stride demonstrating reduced stride lengths (1.00 ± 0.15 m versus 1.29 ± 0.17 m) and average velocities (1.39 ± 0.13 $m·s^{-1}$ versus 1.83 ± 0.22 $m·s^{-1}$) (see Table 6.4). No significant differences were observed for any of the segment or joint angles except for knee angle in which the first stride of the sled pull demonstrated greater knee flexion (103.0 ± 9.4^o versus 113.8 ± 5.9^o) at foot strike.

Table 0.4: Differences in gait kinematics between the heavy sled pull conditions.

	Sled Pull (1st Stride)	Sled Pull (Stride at 2 – 3 m)
Average velocity ($m·s^{-1}$)	1.39 ± 0.13$^{†0.049}$	1.83 ± 0.22
Stride Length (m)	1.00 ± 0.15$^{†0.01}$	1.29 ± 0.17
Stride rate (Hz)	1.41 ±0.14	1.42 ± 0.14
Ground contact time (s)	0.38 ± 0.03	0.35 ± 0.04
Swing time (s)	0.31 ± 0.06	0.33 ± 0.04
Foot Strike (FS)		
Trunk angle (^{o})	76.8 ± 30.4	61.2 ± 13.4
Hip angle (^{o})	81.2 ± 30.4	91.0 ± 16.2
Knee angle (^{o})	103.0 ± 9.4$^{†0.005}$	113.8 ± 5.9
Ankle angle (^{o})	90.6 ± 7.2	84.5 ± 2.1
Toe Off (TO)		
Trunk angle (^{o})	68.8 ± 20.2	60.8 ± 10.7
Hip angle (^{o})	127.2 ± 20.0	133.8 ± 18.4
Knee angle (^{o})	132.8 ± 14.5	137.8 ± 14.0
Ankle angle (^{o})	126.6 ± 19.1	123.3 ± 14.9
Range of Motion (ROM)		
Trunk angle (^{o})	-8.0 ± 11.5	-0.3 ± 8.1
Hip angle (^{o})	46.0 ± 25.9	42.8 ± 13.2
Knee angle (^{o})	29.8 ± 16.0	24.0 ± 11.0
Ankle angle (^{o})	36.0 ± 18.8	38.8 ± 14.3

Data expressed as mean ± SD.
†significantly different to other level of variable ($p < 0.05$)

6.4.4 Exercise Kinetics between Heavy Sled Pull Strides

A significantly higher (p = 0.009) mean ratio of force was associated with the first stride of the heavy sled pull (RF = 37.4 ± 3.8 %) than the stride at 2 – 3 m (RF = 21.7 ± 7.1 %). No significant differences between the first and 2 - 3 m strides were observed for any kinetic variables except for mean of X and mean of Y forces, in which the first stride of sled pull demonstrated significantly higher mean anteroposterior forces (526 ± 162 N versus 271 ± 89 N) and mean medial forces (24 ± 8 N versus -5 ± 22 N) (see Table 6.5).

Table 0.5: External ground reaction forces of the heavy sled pull for the first stride and stride at 2 – 3 m. stride and stride at 2 – 3 m.

	Heavy Sled Pull (First stride)	Heavy Sled Pull (Stride at 2 – 3 m)
Z axis		
Peak vertical force (N)	2154 ± 1054	1821 ± 424
Mean vertical force (N)	1301 ± 348	1269 ± 314
Y axis		
Peak anterior force (N	1044 ± 461	768 ± 170
Mean anterior force (N)	543 ± 166	453 ± 104
Peak posterior force (N)	-627 ± 609	-511 ± 436
Mean posterior force (N)	-240 ± 192	-183 ± 180
Mean of Y forces (Fh) (N)	526 ± 162$^{\dagger 0.029}$	271 ± 89
X axis		
Peak medial force (N)	380 ± 216	247 ± 102
Mean medial force (N)	110 ± 43	83 ± 43
Peak lateral force (N)	-309 ± 167	-224 ± 89
Mean lateral force (N)	-97 ± 58	-89 ± 44
Mean of X forces (N)	24 ± 8$^{\dagger 0.007}$	-5 ± 22
Total resultant ground reaction force (Ftot) (N)	1405 ± 379	1301 ± 310
Mean ratio of forces applied onto the ground (%)	37.4 ± 3.8$^{\dagger 0.009}$	21.7 ± 7.1

Data expressed as mean ± SD.
†significantly different to other level of variable (p = < 0.05)

Group mean average force-time curves (normalised to percentage of mean lift time) obtained with heavy sled pulling at first stride and stride at 2 - 3 m are presented in Figure 6.5. Greater fluctuations in the magnitude of forces are clearly observed in the vertical axis in the sled pull stride at 2 – 3 m.

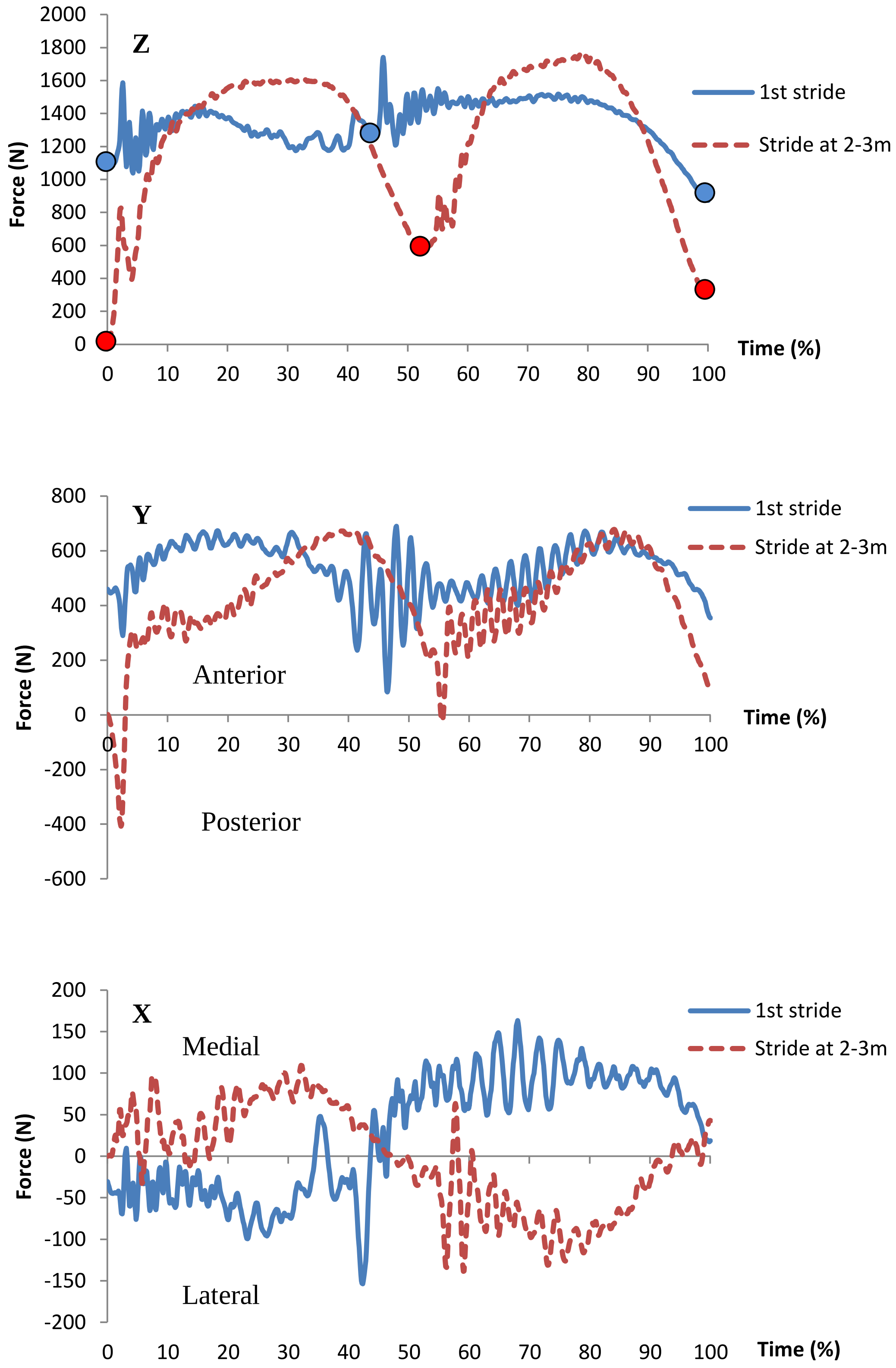

Figure 0.5: Group mean vertical (top), anterior/posterior (middle) and medial/lateral (bottom) force-time curves (normalised to percentage of mean lift time) for the sled pull conditions (first stride and stride at 2 – 3 m) obtained with a 70% 1RM squat load. Circles indicate left or right foot strikes in the sled pull conditions.

6.5 Discussion

Since the heavy sled pull is the most commonly used strongman implement used by coaches in strength and conditioning practice as a means of performance enhancement (Winwood, et al., In Press-b), it is important to obtain data on the heavy sled pull that can provide insight into its effectiveness as a conditioning stimulus. The aim of this study was to gain a greater understanding of the acute stresses that the heavy sled pull imposes on the system and the likely chronic adaptations to this form of training. To achieve this, the kinetic and kinematic characteristics of the sprint-style heavy sled pull (first stride and stride at 2 – 3 m) were quantified, with the start of the sled pull (start of concentric phase to maximal knee extension) compared with the back squat.

Results of the present study were consistent with the initial hypotheses, whereby the heavy sled pull (from start to MKE) demonstrated significantly greater peak (810 ± 174 N versus 126 ± 73 N) and mean anteroposterior (propulsive) forces (555 ± 107 N versus 43 ± 22 N) than the squat (respectively) and the squat demonstrated significantly greater peak (3503 ± 1286 N versus 1736 ± 463 N) and mean vertical forces (2579 ± 648 N versus 1326 ± 364 N) than the heavy sled pull (start to MKE) (respectively). Significant differences ($p < 0.001$) in the mean ratio of forces (RF) were evident with the squat demonstrating that total force was applied vertically (RF = 0.2 ± 0.3 %) compared to the more horizontal orientation (RF = 39.3 ± 5.9 %) associated with the start of the heavy sprint-style sled pull.

Research has demonstrated that both vertical and propulsive ground reaction force impulses ($F \times \Delta t$) are important variables that contribute to sprint velocity (Hunter, et al., 2004; Hunter, Marshall, & McNair, 2005; Weyand, Sternlight, Bellizzi, & Wright, 2000). Producing larger impulse in a vertical direction during ground contacts would result in greater vertical velocity of the centre of mass at take-off which subsequently leads to a longer flight time (Hunter, et al., 2004). However, spending an unnecessarily long time in the air may not be desirable, especially in the acceleration phase, because an athlete can only horizontally accelerate their centre of mass when applying a force to the ground. Researchers have suggested that propulsive anteroposterior ground reaction forces may be the greatest contributor to sprint performance during un-resisted sprint starts (Brughelli, et al., 2011; Hunter, et al., 2005; Kawamori, Nosaka, & Newton, 2013) and that weighted sled towing with heavier loads can improve sprint acceleration performance by teaching athletes to produce larger horizontal or resultant GRF impulse (Cottle, Carlson, & Lawrence, In Press; Kawamori, et al., In Press). The ground reaction force data from the present study gives insight into the potential training adaptations associated with the squat and heavy sled pull.

The results of this study revealed significant biomechanical differences between the start of the heavy sled pull and squat. Significant differences were observed in absolute trunk angles (38.8 ± 5.2^o versus 101.4 ± 5.7^o) at the start of the concentric phase. Such a result was expected due to the predominantly horizontal and vertical directional movement patterns associated with the heavy sled pull and squat, respectively. The strongman athletes selected a significantly wider stance width for the squat (51.0 ± 10.0 cm) compared to 40.9 ± 9.8 cm for the heavy sled pull. The squat stance width in the present study was similar to those reported among power-lifters for traditional stance widths (48.3 ± 3.8 cm) (Swinton, Lloyd, Keogh, Agouris, & Stewart, 2012).

An interesting finding in this study was that at the start of the concentric phase, squat and sled pull relative hip (57.0 ± 9.7^o versus 65.6 ± 12.6^o) and ankle angles (81.0 ± 7.3^o versus 76.0 ± 17.3^o) were somewhat similar. However greater knee extension (95.8 ± 18.5^o versus 62.6 ± 6.3^o) was observed at the start of the sled pull. The greater knee extension seen at the start of the sled pull may provide athletes with a more optimal position to generate propulsive forces based on the muscles being at a more favourable length to take advantage of the length-tension relationship. The greater knee flexion angle seen in the squat was attributed to the participants' familiarity with power-lifting competition rules whereby a legal squatting depth requires the hip joint to pass below that of the knee. As a result, greater range of motion was observed in hip (106.0 ± 9.3^o versus 51.8 ± 19.0^o) and knee joints (104.8 ± 9.8^o versus 37.4 ± 14.7^o) for the squat. Recent research has demonstrated that deep squat (0 - 120^o of knee flexion) training (with loads of 5 -10 RM) resulted in greater increases in front thigh muscle CSA, isometric knee extension strength (at 75^o and 105^o knee extension) and squat jump performance than 12 weeks of shallow squat training (with loads of 5 -10 RM) (Bloomquist, et al., 2013). The findings of the present study and those of Bloomquist et al. (2013) could suggest that the heavy sprint-style sled pull may not be as effective at developing aspects of muscular function and performance that are associated with the full range back squat. Future studies could investigate the training effects of heavy sled pulling on strength, power, speed and body composition measures to give insight into the mechanical and morphological adaptations associated with heavy sled pulling.

The present study sought to provide further insight into the heavy sled pull by providing kinematic and kinetic data of the first stride and stride at 2 – 3 m. Relatively few significant differences were apparent between the two sled pull phases. The first stride of sled pull was associated with significant shorter stride lengths (1.00 ± 0.15 m versus 1.29 ± 0.17 m) and slower average velocities (1.39 ± 0.13 $m{\cdot}s^{-1}$ versus 1.83 ± 0.22 $m{\cdot}s^{-1}$) than the stride at 2 – 3 m. Greater knee flexion (103 ± 9.4^o versus 113.83 ± 5.9^o) was also observed at foot strike in the first stride. Such results are consistent with previous investigations of unresisted (Brughelli, et al., 2011) and resisted sprinting (Cronin, et al., 2008) whereby velocity and stride length increase and joint range of motion may decrease with increased distance.

Comparable stride rates (1.42 ± 0.14 Hz versus 1.45 ± 0.50 Hz) were seen in this study at 2 – 3 m to that (at 2.5 m) of Keogh and colleagues (2010b) in which six resistance-trained athletes performed three 25-m heavy sled pull trials. Differences were apparent with athletes in the present study demonstrating greater average velocities (1.83 ± 0.22 $m{\cdot}s^{-1}$ vs 1.04 ± 0.30 $m{\cdot}s^{-1}$), stride lengths (1.29 ± 0.17 m versus 0.74 ± 0.28 m), swing times (0.33 ± 0.04 s versus 0.25 ± 0.06 s) and shorter ground contact times (0.35 ± 0.04 s versus 0.48 ± 0.23 s) than Keogh and colleagues (2010b). Loading (70%1RM squat versus an absolute load of 171.2kg), environmental factors (laboratory versus outdoors course), and strongman training experience and competition level, may explain the differences observed in these studies.

Relatively few significant differences were observed between the ground reaction forces of the first stride and stride at 2 – 3 m of the heavy sled pull. The first stride was associated with greater mean forces in the anterior-posterior (526 ± 162 N versus 271 ± 89 N) and medial-lateral (24 ± 8 N versus -5 ± 22 N) axis. The mean ratio of force (%) results were consistent with our initial hypothesis whereby significant differences ($p < 0.01$) were evident between the first stride and stride at 2 – 3 m (37.4

± 3.8 % versus 21.7 ± 7.1 %) of the heavy sled pull (respectively). Such differences may reflect the kinematics associated with these phases. The greater horizontal body position seen in the first stride (i.e. 125 % greater trunk angle at foot strike) would allow for greater anterior-posterior propulsive forces to be applied than the more upright position associated with the stride at 2 – 3 m. The mean ratio of forces for the heavy sled pull's first stride is comparable to those reported for the second step ground contact with sled towing with loads of 30% body mass (RF = 39.0 ± 1.6 %) (Kawamori, et al., 2014), but higher than those reported for unresisted sprinting (RF = 28.0 ± 1.6 %) and sled towing with loads of 10% body mass (RF = 31.4 ± 0.6 %) (Kawamori, et al., 2014). The results of this study and the studies of Kawamori and colleagues (Kawamori, et al., 2014; Kawamori, et al., In Press) demonstrate that the heavy sled pulling with loads equal to or greater than 30% body mass may be an efficient training stimulus to teach athletes to produce ground reaction force more horizontally, which is an important factor to sprint acceleration performance (Kugler & Janshen, 2010; Morin, et al., 2011).

An interesting finding in this study was that observations of ground reaction force data showed reduced forces in all three axes for the heavy sled pull at 2 – 3 m compared to the first stride. Such results may be attributed to friction and the force-velocity relationship. While the present study used carpet attached underneath the sled on a linoleum floor, a greater force was required at the start of the sled pull to initiate movement to overcome the force of static friction (Ozkaya & Nordin, 1999). Once this static frictional force was overcome, less force was needed to continue to move the sled as the coefficient of sliding friction was less than that of static friction (Baechle & Earle, 2008). Differences in the coefficient of friction (0.21 to 0.58 μ) have been shown to make substantial differences in 30 m weighted sled (55 kg) towing times (Linthorne & Cooper, 2013). In addition, the shorter ground contact times (0.35 ± 0.04 s versus 0.38 ± 0.03 s) and higher velocity (1.83 ± 0.22 ms^{-1} versus 1.39 ± 0.13 ms^{-1}) associated with the heavy sled pull stride at 2 – 3 m would indicate greater rates of concentric muscle shortening. Literature has demonstrated that as the velocity of the concentric muscle shortening increases, the cycling rate of the myosin-actin cross-bridges increases, leaving fewer cross-bridges attached at one time resulting in a decrease in force (Huijing, 1992). Coaches considering using heavy sled pull with their athletes need to pick training loads based on surface type, demands of the sport and what part of the force velocity curve they are trying to develop within their athletes.

6.6 Conclusion

The results of this study provide coaches with the first combined description of the heavy sled pull's kinetic and kinematic characteristics and how these compare to a common lower body exercise, the back squat. The heavy sled pull and squat force profiles show that these exercises are effective conditioning exercises to generate high propulsive and vertical forces (respectively). The heavy sled and squat may both have some advantages over each other as effective conditioning tools to develop different aspects of muscular performance. Coaches who wish to utilise the heavy sled pull in conditioning practice should be aware that load, training surface, sled, type and position of harness and length of chain may all influence sled pull kinematics and force-velocity characteristics. Coaches should consider individualised exercise prescription with a sports specific approach to elicit optimal neuromuscular adaptations. Future longitudinal training studies are needed to investigate the chronic effects of heavy sprint-style sled pulling on speed and player performance, especially those athletes in collision sports such as rugby or American football where higher levels of sprint momentum are needed to make and break tackles.

CHAPTER 7. A BIOMECHANICAL ANALYSIS OF THE LOG LIFT AND COMPARISON WITH THE OLYMPIC CLEAN AND JERK

7.1 Prelude

The log lift is becoming increasing utilised in strength and conditioning practice, however, no peer-reviewed literature has examined the kinematics and kinetics of the log lift. Chapter 6 provided coaches with a biomechanical description of the heavy sprint-style sled pull and provided insight into the kinetic and kinematic determinants of this exercise. The heavy sprint style sled pull was found to generate greater anterior-propulsive forces compared to the squat with the same given load. The production of anterior-propulsive forces may be beneficial in sports where higher levels of sprint momentum are needed to make and break tackles. This chapter compares the kinematics and kinetics of the log lift with the clean and jerk. Such an analysis will allow for a more detailed understanding of the log lift, providing information for athletes and practitioners of the mechanical stresses that log lift training imposes on the body and the likely chronic adaptations to this form of training. The kinetic data presented on the log lift and clean and jerk exercises will provide the necessary information to help equate loading between these exercises for the training study (Chapter 8).

Winwood, P. W., Cronin, J. B., Brown, S. R. & Keogh, J. W. L. (under 1st review). A biomechanical analysis of the log lift and comparison with the clean and jerk. *International Journal of Sports Science & Coaching*.

7.2 Introduction

Strongman is a sport similar to weightlifting, bodybuilding and power-lifting in which weight training is the primary form of training (Winwood, et al., 2011). The log lift is a popular strongman event performed by strongman athletes both in training and competition (Winwood, et al., 2011). The event requires athletes to lift the log off the ground and raise it above the head with elbows and knees extended. The log lift performed at strongman events can range from maximal strength (i.e. 1RM lifts) events to strength endurance events with athletes performing as many repetitions as possible in a specified time, generally 60-90 seconds with a specified load. Since the log lift consists of cleaning the log from the ground and pressing it overhead, it is deemed to be a functional strength and conditioning exercise because of the increased need for total body stabilisation (Waller, et al., 2003).

The log lift would appear similar to the clean and jerk but is performed with a neutral grip, which may help decrease the risk of shoulder injury as the hands and elbows are more anterior to the shoulder (Durall, et al., 2001; Ellenbecker, 2006). Similar to the weightlifting movements, the log lift requires forceful triple extension at the ankle, knee and hip, which is biomechanically similar to movements found in a variety of sports (Canavan, Garrett, & Armstrong, 1996; Garhammer & Gregor, 1992; Hori, Newton, Nosaka, & Stone, 2005). The log lift, as with the weightlifting exercises requires rapid acceleration of the resistance that occurs with no intention to decelerate the resistance at the end of the range of motion. Thus, the log lift, from a biomechanical perspective may be an excellent method to train high-load total-body speed strength.

The log lift may have some advantages over traditional weightlifting movements. Weightlifting movements such as the clean and jerk are very complex and contain a high degree of technical difficulty (Hedrick & Wada, 2008). Unlike the clean and jerk, the log lift contains two retrieve phases. In the first retrieve lifters lift the log onto the thighs after the first pull and then prepare for the second pull by squatting down with the log resting on the thighs. The squat position allows the lifter to position the log where forceful hip, knee and ankle extension can be used to roll the log up the body into the second retrieve. Since the log can be rested on and rolled up the body, the log lift may be less technically demanding than weightlifting movements. The log lift may therefore be seen as possible alternative or as a regression from the clean and jerk for strength and conditioning coaches wanting to improve athlete’s strength and power development. Recently researchers (Winwood, et al., In Press-b) reported that 88% (n = 193) of strength and conditioning coaches used strongman implements in the training of their athletes with the steel logs ranked the ninth most common implement used by coaches.

To date, very few studies have investigated the strongman log lift. Studies have investigated how strongman competitors train (Winwood, et al., 2011) and the injury epidemiology associated with strongman training (Winwood, et al., 2014). While these studies provided valuable insight into how strongman athletes train with the log (e.g. reps, sets, loads etc) and the sites of injuries associated with performing log lifts, no biomechanical studies have investigated the log lift. Since the log lift is now being used in strength and conditioning practice as a means of performance enhancement, it is important for practitioners to understand the kinematics and kinetics of this event to better appreciate the potential stresses this event places on the body. Such data would give practitioners a greater understanding of the acute stresses that the log lift imposes on the system and the likely chronic adaptations to this form of training. Therefore the purpose of this study was to examine the kinetic and kinematic characteristics of the log lift and make comparisons with the clean and jerk, as the clean and jerk is a common weightlifting exercise used by strength and conditioning coaches to enhance lower body strength and power and is comparable to the movements associated with the log lift. Such an analysis is analogous to recently published papers by Winwood and colleagues (In Press-a) comparing strongman events to similar traditional exercises. These types of studies may also help equate loading and time under tension in future training studies wishing to compare exercises such as log lift pull versus the clean and jerk on aspects of muscular function and performance. It was hypothesised that the log lift would show similar kinetic characteristics to the clean and jerk but kinematic differences would exist between the lifts. It was surmised that the diameter of the log, being much larger than a standard Olympic barbell, would change lifting kinematics because the log cannot be kept as close to the body as that of a traditional barbell.

7.3 Methods

7.3.1 Experimental Approach to the Problem

A cross-sectional descriptive design was used to quantify and compare the kinematics and kinetics of the log lift and clean and jerk. The participants were well-trained strongman athletes with extensive experience performing the traditional and strongman lifts. Data were collected for each participant over two sessions separated by one week. Session 1 was performed in the strength and conditioning laboratory and involved 1-repetition maximum (1RM) testing in the clean and jerk. Session 2 was performed in the biomechanics laboratory where participants performed repetitions in the clean and jerk and log lift (respectively) on force plates using loads of 70%1RM. Kinematics and ground reaction force kinetics were recorded during the second session.

7.3.2 Participants

Six male strongman athletes (four national and two regional level athletes) volunteered to participate in this study, a summary of the participant's characteristics are presented in Table 7.1. All participants regularly performed 1RM testing as part of their training and had an extensive strength training background; including experience with the squat, deadlift, clean and jerk and strongman events including the log lift. The study was conducted two weeks before a regional strongman competition, where the majority of athletes were at the end of a training cycle aimed at improving their previous competition performance. To be eligible to participate in this study the strongman athletes had to have at least 2-years of strongman training experience, competed in at least one strongman competition and be injury free. Prior to participation, all aspects of the research were verbally explained to each participant, written informed consent was obtained and a coded number was assigned to each participant to ensure the data remained anonymous. Full ethical approval was granted for all procedures used in this study by the Auckland University of Technology Ethics Committee (12/311).

7.3.3 One-Repetition Maximum Testing

No supportive aids beyond the use of a weightlifting belt and chalk were permitted during the test. The warm up, loading increments and rest periods used were according to previously established protocols (Wilson, 1994). Maximum strength was assessed by a 1RM performed with a free-weight Olympic-style barbell. This form of strength assessment has been found to be highly reliable (ICC = 0.94) with resistance trained subjects (Ritti-Dias, et al., 2011). Completed lifts in the clean and jerk were recognised when the participants were standing still with feet shoulder width apart, the knees and elbows extended and the bar or log overhead.

7.3.4 Traditional and Strongman Testing

Before performing the lifts, participants engaged in a self-selected total body dynamic warm-up similar to their specific weight training and competition warm-up procedures. Generally this began with two light sets of each lift (e.g., <40%1RM) for 6-10 repetitions. All the participants then performed testing loads of each exercise before any data collection. Once suitably prepared, the participants performed a trial of the exercise to commence with a load of 70%1RM. Loading for the log lift (Log 58.1 kg, length 2355 mm, diameter 165 mm, handle thickness of 33 mm diameter, Getstrength, Auckland) was determined by the participants 70%1RM clean and jerk. Participants were asked to perform the clean and jerk and log lift as explosively as possible. The 70%1RM load was utilised in this study as this load has been shown to elicit the highest average and peak power outputs in the power clean (Kawamori, et al., 2005).

Participants could choose any technique they wished for the log lift (spilt jerk or push press) providing that, for a repetition to be counted, it had to start from the floor and required the participant to be standing upright with feet together and knees locked and elbows extended overhead. Two participants chose to perform the push press for both the clean and jerk and log lift. The lifts were performed in a consecutive order (clean and jerk and log lift). Participants were allocated a two minute rest period between trials. A longer rest period of up to five minutes was available between trials if the subject felt fatigued. Consistent verbal encouragement was provided during testing sessions with the participants frequently reminded to perform the lifts as fast as possible. Shoes worn by participants during testing were those that were typically worn in their strongman training.

7.3.5 Instrumentation

Twelve markers were bilaterally placed over the base of the third metatarsal, lateral malleoli, lateral femoral condyles, greater trochanter, anterior superior iliac spine, and superior boarder of the acromion process. Two Sony (HDR – CX 190E) cameras (Tokyo, Japan)) were used to track the coordinates of reflective markers, adhered to the body, during the various trials at a sample rate of 60 Hz. A Bertec force plate (Model AM6501, Bertec Corp., Columbus, OH, USA) was used to collect synchronised ground reaction forces at 1000 Hz. A diagrammatic representation of the 2 cameras and force platform set-up is presented in Figure 7.1. Vicon Nexus (Version 1.8.1, Vicon Inc., Denver, CO, USA) was used to process the ground reaction force data and bar path trajectories. Ground reaction force data and bar path trajectories were filtered using a fourth order low-pass digital Butterworth filter with a cut-off frequency of 6 Hz.

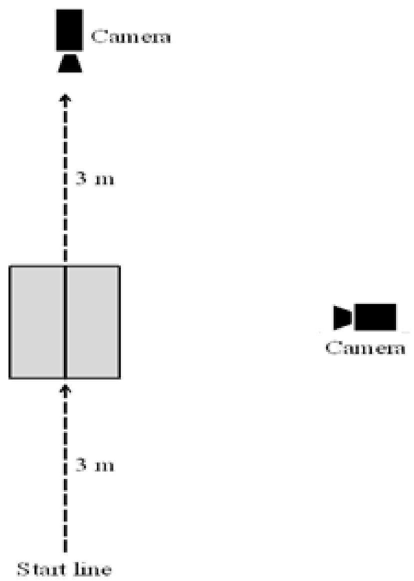

Figure 0.1: Sony camera and force platform set up.

7.3.6 Data Analysis

Four segment/joint angle (trunk, hip, knee and ankle) variables were calculated. Clean and jerk and log lift angles were recorded at lift off (LO), top of first pull (TFP), start of second pull (SSP), middle of the second pull at maximum point of plantarflexion, (MSP), top retrieve (point at which bar or log touches top of chest) (TR), bottom of dip and drive (BDD) and at lift completion (LC) (see Figure 7.2). The internal hip, knee and ankle angles (joint angles) were measured along with the trunk angle in relation to the horizontal axis. A general measure of the range of motion (ROM) of these joint/segments was obtained by subtracting the angle at lift completion from that at initial lift off. 2D kinematics for the trunk, hip, knee and ankle angles were calculated for the right side and were analysed in Kinovea (version 0.8.15, www.kinovea.org) Intra-rater reliability of Kinovea for determining similar lower body joint angles has been shown to be high (ICC = 0.96 – 0.99; typical error 1-2^{o}) (Bowerman, et al., 2013). Bar path kinematics and force data were normalised for time using ensemble averaging in Microsoft Excel 2007. Peak bar/log vertical velocities were calculated for the first pull, second pull and jerk/press. Bar path trajectories were presented as vertical and horizontal displacements from the initial bar/log starting point. Forces were presented as peak and mean values. Forces in the X and Y axis were calculated as medial (positive) and lateral (negative), and anterior (positive) and posterior (negative). Sum of mean forces in the X and Y axes were calculated as the total mean (e.g. X = medial + lateral forces). A definition for all the kinematic and temporal variables (adapted from Keogh et al. (2014)) is given below:

Peak vertical velocity ($m.s^{-1}$): The highest vertical velocity value of the bar/log during the lift.

Trunk angle (°): The internal angle subtended from shoulder and hip to the horizontal axis, with larger values indicating a more vertical trunk position.

Hip angle (°): The internal angle subtended from the shoulder, hip and and knee markers, with increasing values indicating greater hip extension.

Knee angle (°): The internal angle subtended from the hip, knee and ankle markers, with 180° indicating full knee extension.

Ankle angle (°): The internal angle subtended from the knee, ankle and toe, with increasing values indicating plantarflexion.

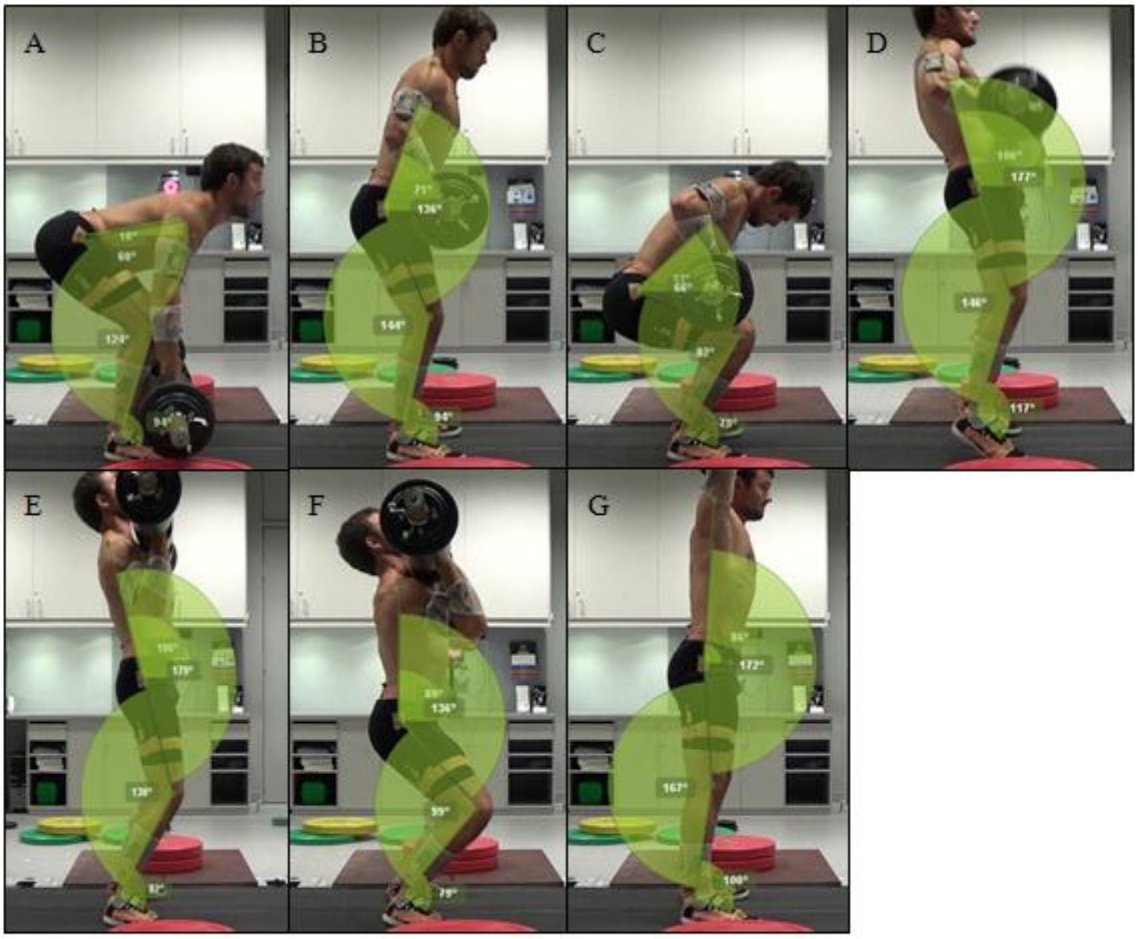

Figure 0.2: Pictorial representation of the four angles measured at; A) lift off (LO); B) top of first pull (TFP); C) start of second pull (SSP); D) middle of the second pull (at maximum point of plantarflexion) (MSP); E) top retrieve (point at which log touches top of chest) (TR); F) bottom of dip and drive (BDD) and; G) at lift completion (LC) in the log lift.

7.3.7 Statistical Analyses

Means and standard deviations were used as measures of centrality and spread of data. Two-tailed paired t-tests were used to determine if any statistical differences existed between the kinematics and ground reaction forces between the log lift and clean and jerk from lift off to lift completion. Statistical significance was set at $p \leq 0.05$. All analyses were performed using IBM Statistical Package for the Social Sciences (Version 20.0, SPSS for Windows).

7.4 Results

Descriptive characteristics of all strongman athletes are presented in Table 7.1. On average strongman athletes trained four times a week for ninety minutes per session which totalled 6.4 hrs of strongman/resistance training per week.

Table 0.1: Demographics, training characteristics and strength measures (mean ±SD) for strongman athletes.

	All Strongman athletes (n = 6)
Demographics	
Age (y)	24.0 ± 3.9
Height (cm)	181.6 ± 9.4
Body mass (kg)	112.9 ± 28.9
Training	
Resistance training experience (y)	6.5 ± 2.7
Strongman implement training experience (y)	2.7 ± 1.6
Number of resistance training sessions per week	4.2 ± 1.2
Average time of resistance training session (min)	90.8 ± 30.4
Strength (1RM)	
Clean and Jerk (kg)	116.7 ± 20.4
Clean and Jerk (kg/kg.bw)	1.05 ± 0.12

7.4.1 Clean and Jerk and Log Lift Kinetics

Relatively few significant kinetic differences were found between the clean and jerk and log lift (see Table 7.2). The clean and jerk demonstrated significantly greater (35%) mean posterior forces.

Table 0.2: Lifting kinetics between the clean and jerk and log lift.

	Clean and Jerk	Log Lift
Z axis		
Peak vertical force (N)	4616 ± 1486	4552 ± 1306
Mean vertical force (N)	1921 ± 385	1940 ± 424
Y axis		
Peak anterior force (N)	1433 ± 1173	1238 ± 899
Mean anterior force (N)	82 ± 31	76 ± 36
Peak posterior force (N)	-1431 ± 1096	-1257 ± 1015
Mean posterior force (N)	-91 ± 27†0.034	-67 ± 14
Mean of Y forces (N)	2 ± 3	1 ± 1
X axis		
Peak medial force (N)	654 ± 484.	592 ± 403
Mean medial force (N)	48 ± 32	44 ± 11
Peak lateral force (N)	-741 ± 616	-803 ± 555
Mean lateral force (N)	-43 ± 17	-43 ± 10
Mean of X forces (N)	2 ± 3	2 ± 2

Data expressed as mean ± SD.

†significantly different to other level of variable

Pictorial representations of group mean ground reaction force curves (normalised to percentage of mean lift time) for the clean and jerk and log lift are presented in Figure 7.3. The clean and jerk and log lift are very similar for all the lifting phases.

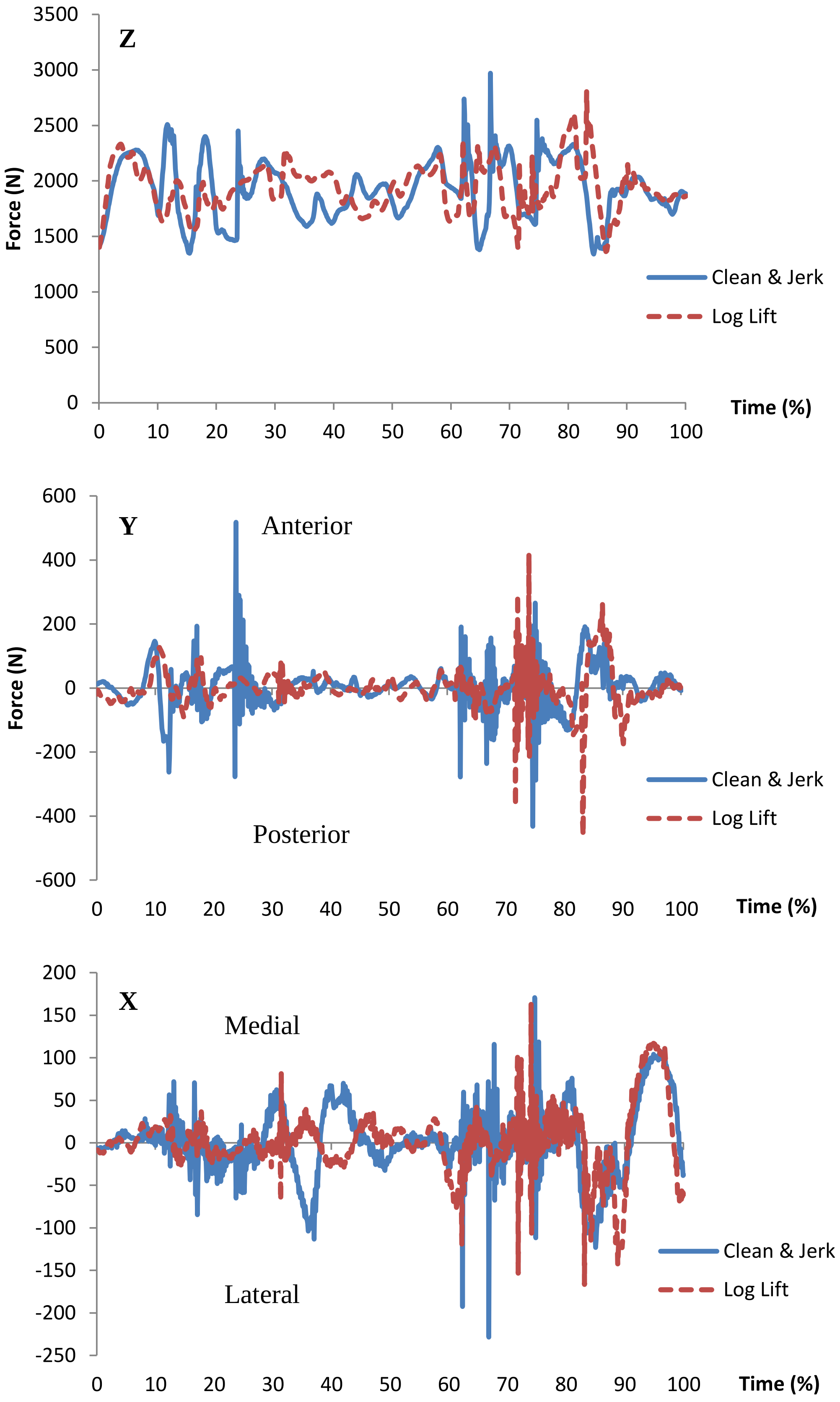

Figure 0.3: Group mean vertical (top), anterior/posterior (middle) and medial/lateral (bottom) force-time curves (normalised to percentage of mean lift time) obtained with a 70% 1RM load for the clean and jerk and log lift.

7.4.2 Lifting Kinematics between the Clean and Jerk and Log Lift

The kinematic data can be observed in Table 7.3. The differences in stance width between the clean and jerk and log lift at lift off (40.3 ± 5.1 cm versus 40.7 ± 4.3 cm), top retrieve (42.4 ± 11.3 cm versus 40.2 ± 6.4 cm) and lift completion (35.9 ± 6.3 cm versus 37.9 ± 5.8 cm) (respectively) were found to be non-significant ($p > 0.05$). However, significant kinematic differences were apparent between the clean and jerk and log lift throughout the lifting phases except for lift completion. Trunk angles were significantly different throughout the lifting phases between the lifts with, greater trunk (24%) and hip ROM (9%) associated with the log lift as compared to the clean and jerk. At 'top retrieve' the log lift was found to have significantly greater trunk (17%), hip (15%) and knee (12%) extension than the clean and jerk.

Table 0.3: Kinematics of trunk, hip, knee and ankle angles performed from the lift off to lift completion for the clean and jerk and log lift.

	Clean and Jerk	Log Lift
Lift off (LO)		
Trunk angle (°)	$20.5 \pm 10.1^{\dagger 0.014}$	7.0 ± 8.0
Hip angle (°)	$60.0 \pm 5.9^{\dagger 0.0017}$	51.8 ± 6.4
Knee angle (°)	103.5 ± 15.5	114.2 ± 13.9
Ankle angle (°)	85.0 ± 7.8	92.8 ± 8.8
Top of first pull (TFP)		
Trunk angle (°)	$36.7 \pm 5.9^{\dagger 0.046}$	51.7 ± 14.6
Hip angle (°)	101.0 ± 5.2	112.8 ± 16.7
Knee angle (°)	143.0 ± 12.9	135.5 ± 15.2
Ankle angle (°)	$99.8 \pm 4.9^{\dagger 0.028}$	94.2 ± 4.6
Start of second pull (SSP),		
Trunk angle (°)	45.0 ± 8.0	51.3 ± 13.0
Hip angle (°)	108.5 ± 4.9	87.8 ± 28.1
Knee angle (°)	$139.7 \pm 11.1^{\dagger 0.019}$	99.2 ± 24.8
Ankle angle (°)	$96.2 \pm 3.0^{\dagger 0.013}$	84.5 ± 6.1
Middle of the second pull (MSP)		
Trunk angle (°)	$94.0 \pm 9.8^{\dagger 0.048}$	111.3 ± 13.7

Hip angle (°)	164.5 ± 12.9	184.3 ± 19.9
Knee angle (°)	147.0 ± 9.5	144.8 ± 7.2
Ankle angle (°)	122.0 ± 7.5	112.2 ± 11.5
Top retrieve (TR)		
Trunk angle (°)	90.7 ± 6.0†0.002	105.8 ± 2.4
Hip angle (°)	158.0 ± 14.8†0.005	182.3 ± 5.3
Knee angle (°)	124.5 ± 13.4†0.033	138.8 ± 11.1
Ankle angle (°)	82.8 ± 4.6	87.3 ± 8.2
Bottom of dip and drive (BDD)		
Trunk angle (°)	86.5 ± 2.1†0.018	92.8 ± 5.3
Hip angle (°)	142.5 ± 6.2	150.0 ± 13.4
Knee angle (°)	106.3 ± 10.8	106.2 ± 11.5
Ankle angle (°)	81.0 ± 3.9	79.3 ± 2.6
Lift Completion (LC)		
Trunk angle (°)	87.3 ± 4.6	89.7 ± 3.6
Hip angle (°)	175.7 ± 8.1	177.3 ± 8.4
Knee angle (°)	166.3 ± 6.4	166.8 ± 6.1
Ankle angle (°)	100.0 ± 3.9	101.8 ± 6.8
Range of Motion (ROM)		
Trunk ROM (°)	66.8 ± 12.0†0.010	82.7 ± 8.4
Hip ROM (°)	115.7 ± 10.4†0.028	125.5 ± 8.9
Knee ROM (°)	62.8 ± 18.7	52.7 ± 9.3
Ankle ROM (°)	15.0 ± 7.6	9.0 ± 4.6
Peak Bar/Log Vertical Velocity ($m \cdot s^{-1}$)		
First Pull	1.51 ± 0.20	1.35 ± 0.21
Second Pull	2.18 ± 0.17†0.014	1.87 ± 0.26
Jerk/Push press	1.82 ± 0.09†0.002	1.60 ± 0.10
Lift Time (s)	6.20 ±1.96	7.96 ± 3.77

†significantly different to other level of variable p = <0.001 unless specified.

Significantly greater peak bar vertical velocities were achieved for the second pull (17%) and jerk/push press (14%) in the clean and jerk compared to the log lift (respectively). Lifting time was shorter in the clean and jerk (22%) than the log lift however the differences were not statistically significant.

7.4.3 Bar Path Kinematics between the Clean and Jerk and Log Lift

Group mean vertical and horizontal displacements of the bar/log paths for the clean and jerk and log lift are presented in Figure 7.4. Greater horizontal displacements (from the bars' original vertical reference line) are evident in the second pull stage of the clean and jerk and in the log lifts jerk phase.

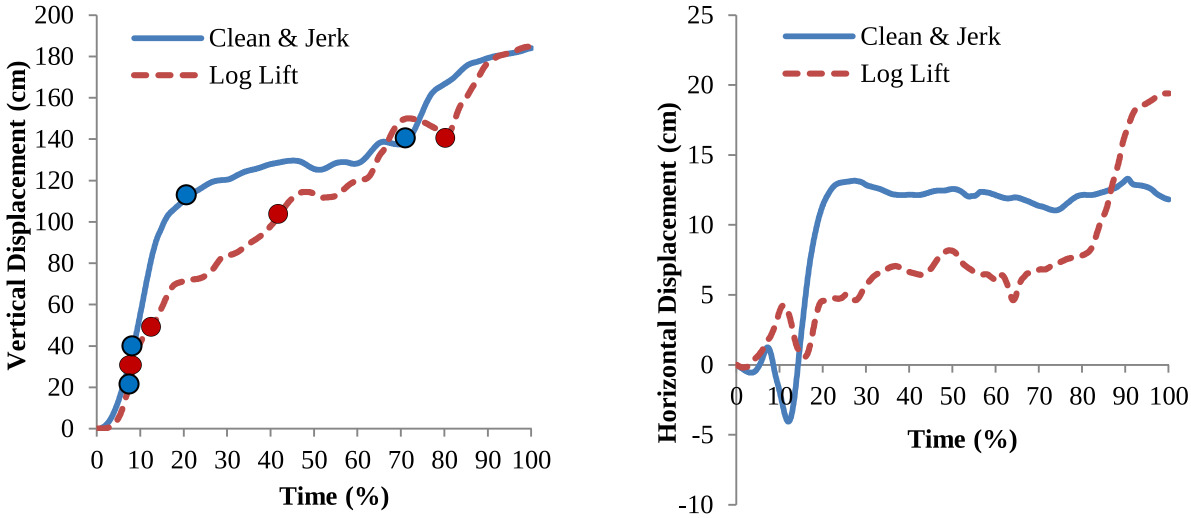

Figure 0.4: Vertical (left) and horizontal (right) displacements of the bar paths for the clean and jerk and log lift normalised to 100% of mean lift time. Circles indicate (from bottom to top) top of first pull, middle of the second pull (at maximum point of plantarflexion), top retrieve and bottom of the dip and drive.

Three different log lifting techniques (log lift with jerk; log lift with push press; and log lift and jerk without squat before second pull) were utilised by strongman athletes in this study. Vertical and horizontal displacements of the varying bar/log paths for the three techniques of log lift are presented in Figure 7.5. The squat pattern is clearly evident in the athlete's vertical displacement graphs (i.e. athletes 1 and 2). Large variations exist in bar/log path horizontal displacements among strongman athletes.

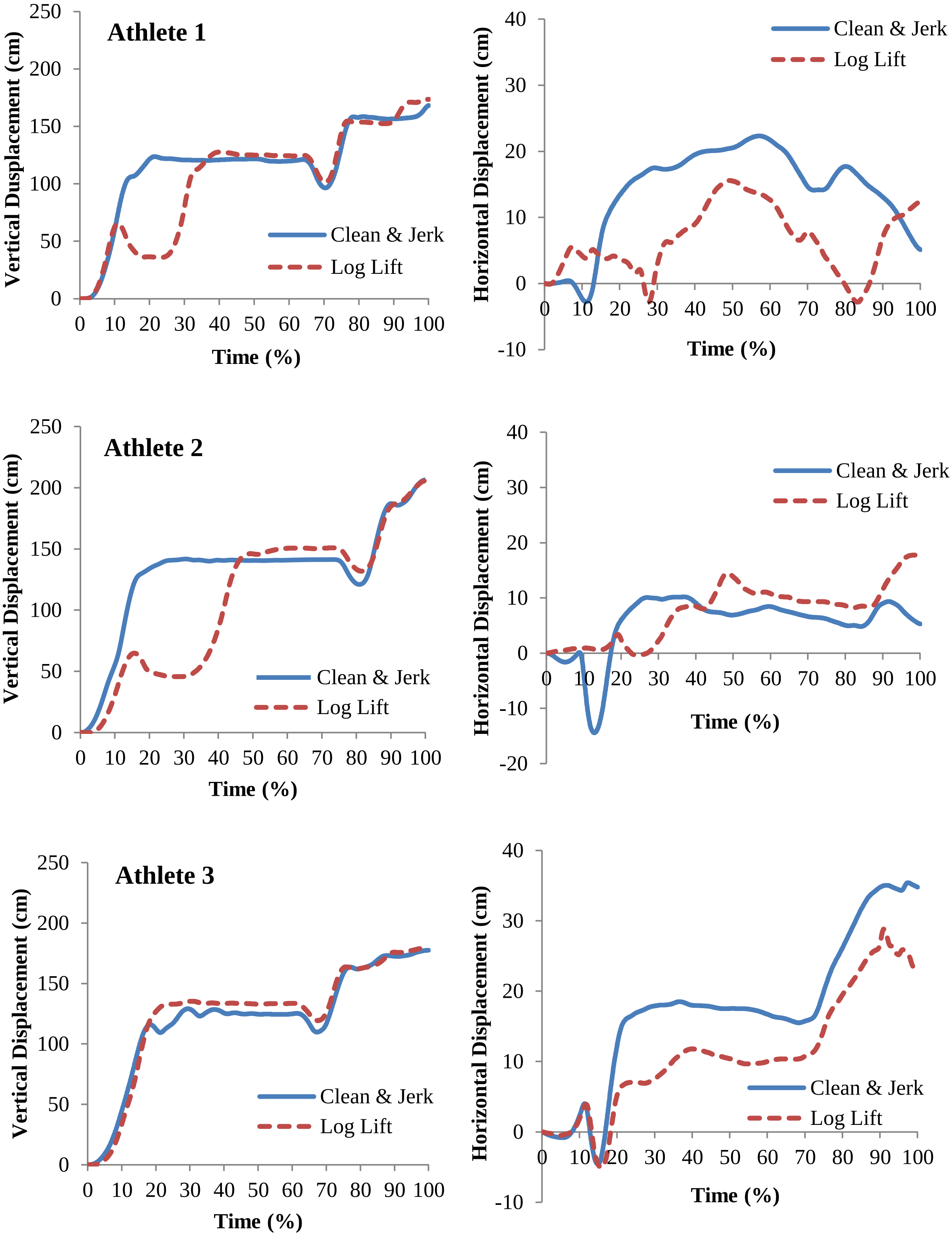

Figure 0.5: Pictorial representations of three log-lifting techniques performed by strongman athletes. Vertical (left) and horizontal (right) displacements of the bar paths normalised to 100% of mean lift time. Athlete 1: log lift with jerk; athlete 2: log lift with push press; athlete 3: log lift and jerk without squat before second pull.

7.5 Discussion

This is the first study to investigate the biomechanical characteristics of the strongman event ‘the log lift’. Since the log lift is now being used by coaches in strength and conditioning practice as a means of performance enhancement (Winwood, et al., In Press-b), it is important to obtain data on the log lift that can provide insight into its effectiveness as a conditioning stimulus. This study sought to understand the acute stresses that the log lift imposes on the system and the likely chronic adaptations to this form of training. To achieve this, the kinetic and kinematic characteristics of the log lift were quantified and compared with the clean and jerk. We hypothesised that the log lift would show similar kinetic characteristics to the clean and jerk but many kinematic differences would exist between the lifts due to the varying diameters of the bar and log.

The results of the present study supported the initial hypotheses, whereby the log lift was found to have very similar ground reaction forces in all three axes to the clean and jerk. The only difference ($P < 0.05$) between the lifts was the greater mean posterior force in the clean and jerk (35%). The similarities in peak and mean vertical and propulsive forces in the present study between the log lift and the clean and jerk demonstrate that the log lift may be an efficient exercise stimulus for improving force production which is advantageous in terms of improving athletic performance. Weightlifting exercises such as the clean and jerk are commonly incorporated into power athletes’ training programmes as the biomechanics of these exercises allow athletes to generate high forces at high velocities thus increasing power capability (Hori, et al., 2005). Researchers have demonstrated kinematic similarities between the propulsive phases in both weightlifting and jumping movements (Canavan, et al., 1996; Carlock, et al., 2004; Garhammer & Gregor, 1992) and significant relationships exist between weightlifting ability and power output during jumping ($r = 0.59$ to 0.93) and sprinting ($r = -0.52$ to -0.76) (Baker & Nance, 1999a; Carlock, et al., 2004; Hori, et al., 2008; Tricoli, Lamas, Carnevale, & Ugrinowitsch, 2005) and tests of agility ($r = -0.41$) (Hori, et al., 2008). Winwood and colleagues (2012) found a clear large correlation between 1RM power clean and log clean and press ($r = 0.67$) repetitions (performed in a 60 second period) in twenty-three male semi-professional rugby players. Despite the different strength qualities measured i.e. maximal strength versus muscular and anaerobic endurance, the large correlation would appear to reflect the similarities in these exercises (i.e. main agonists, specific joint angles and direction of force application, muscle sequence patterns, specific postures, and velocities of movement).

The log lift is very similar to the clean and jerk phases reported in literature (Stone, Pierce, Sands, & Stone, 2006; Storey & Smith, 2012) except in the preparation phase for the second pull. In the clean and jerk, as the barbell passes the knees, the knees shift forward and the barbell and hips move toward each other (Baumann, Gross, Quade, Galbierz, & Schwirtz, 1988). This motion initiates a stretch shortening cycle (known as the double knee bend) and repositions the lifter-barbell system so that the lifter is in a position where they can impart a large force to the barbell rapidly, resulting in a high power output (Baumann, et al., 1988; Enoka, 1979; Garhammer, 1980). In contrast, to prepare for the second pull in the log lift, athletes often place the log on the thighs and then prepare for the second pull by squatting down. This parallel-deep squat position may provide the lifter with three possible advantages during the second pull. It allows the lifter to bring the log close into their upper body which reduces the lumbar resistance moment arm and minimises the distance the log has to travel up the body from the initial start of the second pull to the top retrieve as well as increasing the ability to maximise vertical impulse by increasing the time to produce force. The fact that athletes can roll the log up the body during the second pull may make the log lift less technically demanding than the clean and jerk. However this technique does not incorporate the 'double knee bend' so therefore may not elicit the same strength and power adaptations that are associated with the clean and jerk.

This was evident with peak bar velocity being significantly higher in the clean and jerk in the second pull (16%) and the jerk (14%). Waller and colleagues (2003) suggested that implement diameter changes the mechanics of the press because the log cannot be kept as close to the body as that of a traditional barbell, which may hinder the athletes ability to impart vertical force onto the log. Other factors such as jerking/pressing in a neutral grip with the neck retracted and the head tilted back to minimise horizontal displacement (and lumbar hyperextension) during the jerk/press could also have an impact on log jerk/press velocity. Furthermore, the log lacks the deformation characteristics (attributed to the mechanical properties and physical dimensions) associated with Olympic weightlifting bars, which offer appropriate "spring" for use in weightlifting and competition (Chiu, 2010).

Understanding bar path kinematics is important as researchers have demonstrated that improvements in bar path kinematics lead to improved bar kinetics (i.e. peak force and peak power) (Winchester, Erickson, Blaak, & McBride, 2005). The present study sought to examine the horizontal and vertical displacement characteristics associated with the bar/log paths to determine if differences existed in bar path kinematics. The clean and jerk and log lift were found to have similar bar path kinematics; however a drop in vertical displacement before the second pull in the log lift was clearly evident in the athletes who utilised the squat technique. A range of horizontal displacements were also observed among strongman athletes in both the clean and jerk and log lift. Garhammer and colleagues (1985) suggested that a number of factors can influence the optimum trajectory for an athlete including relative body segment lengths and whether the athlete jumps forward or backward to catch the bar. The results of the present study and that of Garhammer et al. (1985) demonstrate that lifting trajectories are unique to each individual.

Our group mean results were similar to previous findings reported in literature (Garhammer, 1985; Winchester, et al., 2005) in which the movements of the bar and log were generally toward the lifter (positive direction) in the first pull, followed by movement away from the lifter during the second pull (negative direction), and then again toward the lifter (after the point of maximum hip extension associated with the second pull). Interestingly, greater mean horizontal displacements were associated with the clean and jerk in the second pull while greater horizontal displacements were seen in the log press/jerk. Such data supports our initial hypothesis in which we surmised that the diameter of the log would change lifting kinematics because the log cannot be kept as close to the body as that of a traditional barbell. The greater horizontal displacements associated with the log lift jerk/press, supports the views of Waller and colleagues (2003) in regard to implement diameters and pressing mechanics. It could also be argued that the greater horizontal movement associated with the log jerk/press could require greater core stabilisation and overall body balance, however studies are needed to validate such views. Future research could investigate the effect of different log sizes on muscle activity and bar path kinematics.

This study also sought to provide further insight into the kinematics of the log lift by comparing stance widths and joint angles with the clean and jerk during key components of the lifts. Interestingly, no significant differences in stance width were found at lift off, top retrieve and lift completion, however significant differences ($P < 0.05$) in joint and segmental angles were found throughout the lifting phases, except at lift completion. Significant differences were apparent at lift off with the log lift having greater trunk (7.0 ± 8.0^{o} versus 20.5 ± 10.1^{o}) and hip (51.8 ± 6.4^{o} versus 60.0 ± 5.9^{o}) flexion angles than the clean and jerk. The differences in trunk and hip angles at lift off are likely to be attributed to the center of the log being further away from the lifter at the start of the lift to that of the barbell used in the clean and jerk. Greater trunk extension was seen in the log lift at the top of the first pull in which the athletes had to pull the log up higher to clear the knees as opposed to the barbell with the clean and jerk. Greater dorsiflexion (84.5 ± 6.1^{o} versus 96.2 ± 3.0^{o}) and greater knee flexion (99.2 ± 24.8 versus 139.7 ± 11.1) angles were seen in the log lift at start of the second pull which reflected the deep squat position associated with this phase.

Significantly greater trunk extension was also observed in the log lift during the middle of the second pull (↑18%), top retrieve (↑17%) and bottom of the dip and drive (↑7%). In order for athletes to move the log in a vertical direction up the body, greater trunk extension was required to minimise forward horizontal displacement of the log. The large variances associated with the knee ($\pm 24^{o}$), hip ($\pm 28^{o}$) and trunk angles ($\pm 13^{o}$) in the log lift at the start of the second pull demonstrate that strongman athletes utilise various lifting strategies for the second pull with a 70% 1RM clean and jerk load. Interestingly, trunk and hip range of motion was significantly greater (24^{o} and 9^{o} respectively) in the log lift compared to the clean and jerk. Coaches who are trying to develop forceful hip extension in their athletes could find the log lift to be an effective training exercise to achieve this. Future research may wish to investigate the kinematics and kinetics of log lifting with a range of different size logs and loads. Such research would give insight into the force-velocity characteristics of log lifting and the kinematic variances associated with performing log lifts with logs of various diameters and loads.

7.6 Conclusion

The results of this study provide coaches with the first biomechanical description of the log lift's kinetic and kinematic characteristics and how these compare to the clean and jerk. The log lift and clean and jerk force profiles show that these exercises are effective conditioning exercises that allow the generation of high vertical forces. The log lift may be an effective lifting alternative for coaches who have athletes that are not proficient in the clean and jerk and for athletes who may prefer to press with a neutral grip. Coaches who wish to utilise the log lift in conditioning practice should be aware that load, log type and size may all influence log lift kinematics and force-velocity characteristics. Coaches should consider individualised exercise prescription with a sports specific approach to elicit optimal neuromuscular adaptations. Future biomechanical studies are needed to investigate the effect of load and log size on lifting kinematics and kinetics.

CHAPTER 8. THE CHRONIC EFFECTS OF STRONGMAN TRAINING VERSUS TRADITIONAL TRAINING ON ASPECTS OF MUSCULAR FUNCTION AND PERFORMANCE

8.1 Prelude

Understanding the magnitude of transference between programming and performance is critical for strength and conditioning coaches. Such information provides an evidence base, which can be utilised to better stimulate athlete adaptation. The previous biomechanical studies (presented in Chapters 5 to 7) presented the first studies in which the kinematics and kinetics of traditional lifts and strongman events were compared within the same sample of strongman athletes, this providing insight into the acute mechanical stresses these exercises impose on the body. Such information also provides the first data to help accurately equate strongman and traditional training programmes based on load and time under tension. While the previous three studies in this thesis gave insight into the potential acute effects of strongman events, no evidence currently exists on the chronic effects of strongman training on muscular function and performance. Therefore, the purpose of this training study was to determine the efficacy of a strongman conditioning programme in relation to traditional resistance type training. Such information will provide the strength and conditioning coach with a greater understanding of the benefits and limitations of strongman implement training.

Winwood, P. W., Cronin, J. B., Posthumus, L. R., Finlayson, S. J., Gill, N. D. & Keogh, J. W. L. (In Press). Strongman versus traditional resistance training effects on muscular function and performance. *Journal of Strength and Conditioning Research.*

8.2 Introduction

In recent years, the use of strongman training modalities for performance enhancement have become popular in strength and conditioning practice (Bennett, 2008; Corcoran & Bird, 2009; Hedrick, 2002, 2003; Winwood, et al., In Press-b; Zemke & Wright, 2011). This increase in popularity could be attributed to the unique events demonstrated in the sport, the increasing accessibility of the training implements and the opportunity to use these exercises to add variation to resistance training programmes. Generally, gymnasium-based resistance training exercises are performed vertically with two feet side by side. While walking lunges or split stance exercises may offset some of the limitations of the traditional lifts (Keogh, 1999), strongman exercises such as the farmers walk and heavy sled pull may be even more applicable to sporting movements as they often involve unstable and awkward resistances and involve both unilateral and bilateral motion. Stone and colleagues (2007) have suggested that the more similar a training exercise is to actual physical performance, the greater the probability of transfer. Advocates of strongman training (Baker, 2008; Corcoran & Bird, 2009; Hedrick, 2003; Poliquin & McDermott, 2005; Waller, et al., 2003; Zemke & Wright, 2011) have suggested it is more specific than other forms of strength training and may help 'bridge' the gap between gymnasium-based strength training and functional performance. A recent study of 220 strength and conditioning coaches found that 81% believe they had achieved good to excellent results from strongman implement training (Winwood, et al., In Press-b). Such a contention however, is speculative given that no research to the knowledge of these authors has examined the chronic effects of strongman training compared to typical gymnasium-based strength training of athletes.

Articles published on the sport of strongman have provided valuable insight into how strongman implement training may be implemented in strength and conditioning programmes (Bennett, 2008; Hedrick, 2003; Waller, et al., 2003; Zemke & Wright, 2011). Researchers have investigated the metabolic and endocrine responses, and biomechanical (kinematic determinants of performance and lower back/hip loads) demands of strongman exercises (Berning, et al., 2007; Ghigiarelli, et al., 2013; Keogh, et al., 2010b; Keogh, et al., 2010c; McGill, et al., 2009). These cross-sectional studies have provided results suggesting that strongman events could prove useful in improving core strength, power, sprint start and acceleration capabilities, as well as anaerobic conditioning and for increasing energy expenditure. However, an evidence-based approach that uses longitudinal designs to determine the efficacy of strongman training is needed before strength and conditioners find reason to change current training strategies and best practice.

In light of the limitations of the literature reviewed and given that no study has investigated the effectiveness of a strongman resistance programme, the purpose of this study was to compare the chronic effects of strongman implement training versus traditional training on aspects of muscular function and performance. Such a comparison should improve our understanding of the effects of strongman exercises and how they may differ to that of traditional type gymnasium-based approach. It was hypothesised (based on the principle of specificity) that at the end of the training intervention, effect sizes in grip strength and horizontal performance tests e.g. sprinting speed, change of direction (COD) time, medicine ball throw and horizontal jump distance would be greater in the strongman training group, whereas effect sizes in the vertical performance measures including vertical jump height and 1RM strength would be greater in the traditional training group.

8.3 Methods

8.3.1 Experimental Approach to the Problem

A randomised comparative trial was used to compare a traditional resistance and strongman training protocol. Thirty experienced resistance-trained rugby players volunteered to participate in this study. Participants were assessed for body composition, 30 m sprint time, horizontal jump distance, seated medicine ball chest press throw, vertical jump height, grip strength, 15 m sled push and 5-0-5 change of direction (COD) tests (respectively). Baseline testing occurred in week one, after which a supervised seven week strength and power programme was performed twice weekly before final testing in week nine. Changes in the outcome variables after training were compared between groups using independent T-tests and effect statistics.

8.3.2 Participants

Thirty male resistance-trained amateur and semi-professional rugby players volunteered to participate in this study. A summary of the participants characteristics are presented in Table 8.1. All participants regularly performed resistance training as part of their training and had a strength training background (> 1 year). The study was conducted in the participant's off-season where the majority of participants were at the start of a training cycle aimed at improving their strength performance. Participants were excluded if: any medical problems were reported that compromised their participation or performance in this study; and, athletes were taking or had previously taken any performance-enhancement drugs of any kind. All participants provided written informed consent after having being briefed on the potential risks associated with this research. Prior ethical approval was granted by the AUT University Ethics Committee, Auckland, New Zealand. In total, 36 participants were recruited for this study, but, because of injury, transport issues and work and family commitments, only 30 participants completed all parts of the testing and intervention programme. The results of this study are based on the data obtained from these 30 participants. Two injuries were reported as part of the training intervention. One was a minor back muscle sprain associated with the deadlift, which resulted in the participant missing one training session and the other was a shoulder injury associated with strongman training in which the participant had to stop training and subsequently pull out of the study. Adherence to training was 98.6% for both groups. All training for this study was undertaken at a similar time of day with participants instructed to maintain their normal dietary intake before and after each workout. We did not control for nutrition, or hydration levels but participants were told not to make any changes in the above during the intervention and post intervention testing.

Table 8.1: Participant characteristics (mean ± SD).

Parameters	*All Participants (n = 30)*	*Strongman Group (n = 15)*	*Traditional Group (n = 15)*
Age (y)	22.9 ±4.6	23.4 ±5.6	22.5 ±3.4
Height (cm)	180.7 ±6.2	180.1 ±6.8	181.3 ±5.9
Body mass (kg)	92.5 ±13.4	91.2 ±14.8	93.7 ±12.3
Resistance training experience (y)	4.3 ±2.8	3.9 ±2.3	4.7 ±3.3
1RM Strength Measures			
Clean and jerk (kg)	85.1 ±11.8	87.2 ±9.3	81.5 ±14.4
Deadlift (kg)	171.1 ±23.7	181.3 ±18.2	161.8 ±24.1
Military press (kg)	69.1 ±11.4	68.5 ±10.6	69.6 ±12.1
Squat (kg)	142.4 ±25.0	141.1 ±24.0	146.2 ±24.0
Bent over row (kg)	106.0 ±14.2	106.9 ±14.6	108.2 ±11.9
Performance Measures			
30 m sprint speed (s)	4.36 ±0.20	4.35 ±0.20	4.38 ±0.20
5-0-5 COD test (s)	2.39 ±0.12	2.40 ±0.13	2.38 ±0.12
15 m 70 kg sled push (s)	4.03 ±0.33	4.01 ±0.37	4.06 ±0.30
Vertical jump (cm)	58.28 ±8.80	59.87 ±9.52	56.57 ±7.94
Horizontal jump (m)	2.38 ±0.18	2.40 ±0.21	2.35 ±0.16
5 kg MB Chest throw (m)	4.65 ±0.54	4.56 ±0.52	4.76 ±0.56
Grip strength left (kg)	55.68 ±7.85	56.00 ±7.34	55.36 ±8.57
Grip strength right (kg)	56.20 ±8.64	56.33 ±9.66	56.07 ±7.86

8.3.3 Strength Testing

No supportive aids beyond the use of a weightlifting belt and lifting chalk were permitted during the testing. The warm up, loading increments and rest periods used were according to previously established protocols (Wilson, 1994). Movement competency screening of the 1RM strength exercises took place prior to strength testing and instruction was given when required to improve technique. Strength testing was assessed by 1RM - 3RM tests performed with a free-weight Olympic-style barbell. This form of strength assessment has been found to be highly reliable (ICC = 0.94) with resistance trained subjects (Comfort, 2013; Ritti-Dias, et al., 2011). The 1RM test was performed for the clean and jerk and 1RM - 3RM tests were performed for deadlift, military press, squat, and bent over row (respectively). Squat RM was assessed using the methods outlined by Baker (1999b). Completed lifts in the clean and jerk, deadlift and military press were recognised when the participants were standing still and fully upright with the applied load. For the bent over row, participants had to achieve full range of motion of the upper limbs while remaining in a partial squat position with no movement at the hip and knee. The Poliquin formula (Poliquin, 1997) was used to determine the participants predicted 1RM from their 2RM or 3RM values. Percentage of loading for the training intervention was based on the athletes predicted 1RM.

8.3.4 Functional Performance Testing

Before the commencement of functional performance testing participants had their body composition (body mass, body fat percentage and muscle mass (MM), measured and recorded using a bioelectrical impedance machine (InBody230, Biospace). Participants then performed a ten minute standardised warm up prior to testing that consisted of dynamic stretching, and light jogging interspersed with bodyweight exercises. Testing commenced five minutes after the warm up. The testing session involved the determination of the participants 5 m, 15 m and 30 m sprint times (s) from a 30 m sprint, horizontal jump (m), seated 5 kg medicine ball (MB) chest press throw (m), vertical jump height (cm), left and right hand grip strength (kg), 70 kg 15 m sled pushes (s), and 5-0-5 change of direction (COD) test (s). A rest period with a minimum of 10-minutes was provided between each test. Participants performed two; 30 m sprints (CV = 0.6%), 5-0-5 COD tests (CV =

2.2%), grip strength tests (CV = 4.2% and 4.5% for left and right grip strength, respectively), and 15 m sled pushes (CV = 2.9%); and three horizontal jumps (CV = 1.6%), countermovement vertical jumps (CV = 3.2%) and seated 5 kg MB chest press throws (CV = 1.3%). The best result for each test was used for data analysis. All pre-and-post functional performance testing were performed indoors on artificial turf (15 mm underlay/10 mm overlay) at the same time of day. The performance tests chosen for this study have been considered appropriate functional performance tests and conditioning exercises for a variety of athletes and have shown good test-retest reliability (Gabbett, Kelly, & Sheppard, 2008; Harasin, Dizdar, & Markovic, 2006; Maulder & Cronin, 2005; Moir, Button, Glaister, & Stone, 2004; Wang & Chen, 2010).

8.3.5 Strength and Power Assessment

Grip strength was determined with a grip strength dynamometer (TTM Original Dynamometer 100kg, Tokyo). Participants were instructed to hold the dynamometer at their side and pull the handles together with maximal effort for up to three seconds. The countermovement vertical jump (CVJ) and horizontal jump were performed off two feet and with full arm motion. A tape measure was used to determine horizontal jump distance and the Vertec Yardstick (Swift Performance Equipment, Australia) was used to determine jump height. Standing reach measures were subtracted from the Vertec determined jump height to calculate the CVJ displacement. Horizontal jump was measured from the start line (positioned in front of toes) to the nearest point of contact on landing (back of the heel). Participants were required to jump as far forward as possible and land on two feet without falling. Participants were allowed two familiarisation horizontal jumps and were instructed to ‘sink’ into the landing to prevent falling forward.

The 70 kg sled push over 15 m (see Figure 8.1) was measured using SpeedlightV2 wireless dual beam timing lights (Swift Performance Equipment, Australia). Participants started in a bilateral standing stance with the sled poles positioned 0.5 m before the start line. No rocking or backward steps were allowed prior to the start. Participants were instructed to push the sled as fast as possible with maximal effort. Hand pushing position was determined by the first web space with participants standing anteriorly to the sled poles with straight arms at their sides. Timing lights were placed at the start, 5 m, 10 m and 15 m marks. Timing light beams were set at 92.5 cm (top beam) and 68 cm (bottom beam) for all performance test times represented in this study. Push sled times were recorded for total distance and between each split. The 5-kg seated concentric MB chest press throw was performed with the participant sitting on the floor with legs fully extended, approximately 60 cm apart and the back and head against a wall. The ball was held with the hands on the side and against the centre of the chest with the forearms positioned parallel to the ground. Participants were instructed to throw the medicine ball explosively at a 45 degree angle to the horizontal as far as possible while keeping the head and back against the wall. Participants were instructed to throw the MB along a line in which a measuring tape was adhered too. The distance of ball flight was recorded.

Figure 8.1: Pictorial representation of the 70 kg 15 m heavy prowler push.

8.3.6 Speed and Change of Direction Assessment

Speed and 5-0-5 COD ability were measured using SpeedlightV2 wireless dual beam timing lights (Swift Performance Equipment, Australia). For both tests, participants started in a standing split stance, with the toes of the back foot in line with the heel of the front foot, 50 cm before the start line. No rocking or backward steps were allowed prior to the start. Participants were instructed to sprint at maximal effort in the speed and 505 COD tests. For the 30 m sprint test, timing lights were placed at the start, 5 m, 15 m and 30 m marks. Sprint times were recorded for total distance and between each split. For the 5-0-5 COD test, timing lights were placed on the 2 m and 5 m markers and times were recorded when the participant passed through the 5 m and 2 m markers, turned on the line, and returned through the 2 m and 5 m markers. 5-0-5 times were recorded for total distance (10 m) and between each split (0 – 3 m (deceleration), 2 m + 2 m (turning ability), and 2 m to 5 m (acceleration)).

Table 8.2: Outline of traditional and strongman training protocols.

Protocols	*Sets*	*Reps or Distance*	*Total Load*	*Rest*	*Rest Between Exercises*
Traditional Protocol					
Clean and Jerk*	3	5 reps	70% of 1RM	2min	3min
Deadlift	3	5 reps	80% of 1RM	2min	3min
Military Press	3	6 reps	80% of 1RM	2min	3min
Back Squat*	3	5 reps	85% of 1RM	2min	3min
One Arm Row	2	8 reps	30% of 1RM Bent over row	2min	
Strongman Protocol					
Log Lift*	3	5 reps	70% of 1RM Clean and Jerk	2min	3min
Farmers Walk	3	28 m	80% of 1RM Deadlift	2min	3min
Axle Press	3	6 reps	80% of 1RM Military Press	2min	3min
Heavy Sled Pull*	3	25 m	85% of 1RM Back Squat	2min	3min
Arm Over Arm Prowler Pull	2	16 reps (8-each arm)	100% of 1RM Bent over row	2min	

Key: *Perform the exercise explosively, 1RM = One repetition maximum.

8.3.7 Training Programmes

The seven-week training intervention involved participants performing either traditional resistance training or a strongman training programme (Table 8.2). The traditional and strongman exercises were paired based on biomechanical similarity and loads were equated between the two groups. The exercises chosen are commonly performed in strength and conditioning practice, and by strongman athletes for the development of muscular strength and power (Winwood, et al., 2011).

Equal training loads (kg) were used for the log lift and clean and jerk, and the axle press and military press. Loading for the arm over arm prowler pull and one arm row was based on the athletes' perceived rate of exertion (Borg's Scale) during pilot studies, and expressed as a % of 1RM bent over row. For the sled pull and squat, and deadlift and farmers walk loading was equated based on the kinetic data (Linthorne & Cooper, 2013; Winwood, et al., In Press-a). A technical note (p. 171) detailing equations based on time under tension (see Table 8.4) is presented at the end of this chapter. Time under tension is well known to be a factor that determines neuromuscular adaptations (Toigo & Boutellier, 2006). Participants were asked to self-select their movement speed for the farmers walk, deadlift and one arm row but were asked to perform the squat, clean and jerk, log press and heavy sled pull as explosively as possible.

Participants in the strongman group performing the heavy sled pull were instructed to start in a four-point power position and accelerate the sled 25 m over the artificial turf surface as quickly as possible using powerful triple extension of the lower body. For the arm over arm prowler pull (Prowler sled 30 kg, 1400 mm length, 925 mm width) participants were instructed to start in a crouching position and pull the rope (20.0 kg, length 30 m, 32 mm diameter) (Sports Distributors, Tauranga) to the hip with one arm and allow the prowler sled to remain stationary between each pull. For the farmers walk participants were instructed to pick up the bars in each hand and walk forward over a course of 28 m with the rounding of a cone at half way (14 m). Participants could choose any technique they wished for the log lift providing that, for a repetition to be counted it had to start from the floor and the participants had to be standing upright with knees and elbows extended. The lifts were performed in a consecutive order (log lift, farmers walk, axle press, heavy sled pull and arm over arm prowler pull). A longer rest period of up to 5-minutes was made available between sets and exercises in both protocols if the participant felt fatigued. Consistent verbal encouragement was provided during testing sessions with the participants frequently reminded to perform specific lifts as fast as possible. The farmers bars (14.3 kg, length 1160 mm, handle thickness of 33 mm diameter), axle (17.0 kg, length 2150 mm, diameter 2 inches), sled (11.5 kg, length 600 mm, width 400 mm) and log (58.1 kg, length 2355 mm, diameter 165 mm, handle thickness of 33 mm diameter) used in this study were purchased from Getstrength, Auckland. Pictorial representations of the strongman exercises are presented in Figure 8.2.

Figure 8.2: Illustration of various strongman events. A = heavy sprint-style sled pull; B = log lift; C = axle press; D = farmers walk; E = arm over arm prowler pull.

The training programmes required the participants to train for up to 75 minutes bi-weekly on non-consecutive days. The training exercises were performed in a controlled manner and loading was increased by ~2% each week providing the participant could maintain good form. The fourth week was a de-loading week in which participants performed the exercises with the same loads they used in week one. All training sessions were supervised by qualified training instructors and logs of all participants training sessions were recorded. Supplementary training was permitted which consisted of prehabilitation and cardiovascular conditioning. All athletes were encouraged to perform two sessions of prehabilition exercises per week and two cardiovascular training sessions focused on improving aerobic capacity. However, these forms of training were not able to be monitored by the researchers.

8.3.8 Statistical Analyses

The data was explored by a histogram plot, and the normality of distribution was tested using Shapiro-Wilk's test for all groups in this study. Then, descriptive statistics were calculated and reported as mean and standard deviations. The difference in central location (mean) between groups was examined using the independent sample *t*-test. For the data that did not follow a normal distribution, the Mann-Whitney *U*-test was used to determine if the difference between groups was significant. Effect sizes (ES = mean change/standard deviation of the sample scores) were calculated to quantify the magnitude of the performance differences (i.e. pre intervention results - post intervention results) between each of the two groups (i.e. strongman and traditional) (Cohen, 1988). Cohen applied qualitative descriptors for the effect sizes >0.2, >0.5 and >0.8 indicated small, moderate, and large changes, respectively. To counteract the problem of multiple comparisons and the chance of a false positive, significance was accepted at the $p \leq 0.01$ level as a compromise between increasing risk of both Type I (finding statistical between-group significance where none truly exists) and Type II (finding no statistical between-group significance where one truly exists) errors. The 95% confidence interval (95% CI) was also calculated for all measures. All statistical analyses were carried out using SPSS 20.0 for Windows (SPSS Inc., Chicago, IL, USA).

8.4 Results

Overall, all strength and functional performance measures tended to improve with training (0.2% to 7%), thus providing evidence that both training programmes provided positive training adaptations (see Table 8.3). However, no significant ($p < 0.01$) between-group differences were found for the functional performance measures, indicating that there was no statistically significant advantage between traditional and strongman training methods.

With regards to the between group effects traditional training was associated with greater (small-moderate) effect size changes in body fat mass (ES = -0.38), % body fat (ES = -0.38), 1RM squat (ES = 0.47) and deadlift (ES = 0.66), COD turning ability (ES = - 0.38) and total COD time (ES = - 0.25), horizontal jump (ES = 0.56), and sled push performance (ES = - 0.31 to - 0.46) than strongman training. Conversely strongman training was found to elicit small-large greater increases in muscle mass (ES = 0.44), 1RM bent over row (ES =1.10), 5 m (ES = - 0.28) sprint performance and COD acceleration (ES = - 0.33) than traditional training.

Table 8.3: Magnitude of differences between post and pre intervention measures tested between traditional and strongman training groups.

Between-group differences

	Strongman	Traditional	Difference	95% CI	Effect Size
Body Composition					
Body mass (kg)	0.5 ±2.0	-0.5 ±2.3	-1.0 ±0.8	-1.6 to 1.6	0.00
Muscle mass (kg)	-0.4 ±0.8	-0.0 ±1.0	0.4 ±0.3	-0.3 to 1.1	0.44[S]
Body fat mass (kg)	0.3 ±2.0	-0.4 ±1.8	-0.7 ±0.7	-2.2 to 0.8	-0.36[T]
Body fat (%)	0.3 ±2.0	-0.4 ±1.6	-0.7 ±0.7	-2.1 to 0.7	-0.38[T]
1RM Measures					
Clean and jerk (kg)	-7.5 ±5.8	-8.7 ±6.5	-1.2 ±2.6	-6.6 to 4.2	0.19
Deadlift (kg)	-10.4 ±10.9	-17.8 ±11.8	-7.5 ±4.7	-17.2 to 2.3	0.66[T]
Military press (kg)	-6.2 ±6.9	-5.3 ±4.8	-0.9 ±2.5	-4.3 to 6.0	0.15
Squat (kg)	-3.9 ±16.1	-10.9 ±13.7	-7.0 ±6.2	-20.0 to 6.0	0.47[T]
Bent over row (kg)	-14.5 ±9.0	-4.7 ±8.8	9.8 ±3.8	1.7 to 17.9	1.10[S]
Functional Performance Measures					
Sprint Speed					
5 m (s)	0.02 ±0.04	0.01 ±0.03	-0.01 ±0.01	-0.04 to 0.02	-0.28[S]
15 m (s)	0.01 ±0.06	0.01 ±0.04	-0.00 ±0.02	-0.04 to 0.04	-0.06
30 m (s)	0.02 ±0.10	0.01 ±0.06	-0.01 ±0.03	-0.07 to 0.05	-0.18
505 COD Test					
Deceleration (-5m to -2m) (s)	0.01 ±0.03	0.00 ±0.04	-0.00 ±0.01	-0.03 to 0.03	-0.05
Turning ability (-2m to 2m) (s)	0.00 ±0.14	0.05 ±0.10	0.05 ±0.04	-0.05 to 0.14	-0.38[T]
Acceleration (2m to 5m) (s)	0.01 ±0.06	-0.02 ±0.04	-0.02 ±0.02	-0.06 to 0.03	-0.33[S]
Total time (s)	0.01 ±0.13	0.04 ±0.07	0.03 ±0.04	-0.06 to 0.11	-0.25[T]
15 m 70kg Sled Push					
5 m (s)	0.02 ±0.11	0.09 ±0.10	0.07 ±0.04	-0.02 to 0.15	-0.31[T]
10 m (s)	0.04 ±0.18	0.10 ±0.14	0.05 ±0.06	-0.07 to 0.17	-0.33[T]
15 m (s)	0.05 ±0.20	0.14 ±0.16	0.08 ±0.07	-0.06 to 0.22	-0.46[T]
Lower body Leg Power					
Vertical jump (cm)	-4.13 ±6.35	-3.86 ±5.37	-0.28 ±2.18	-4.20 to 4.75	0.09
Horizontal jump (m)	-0.03 ±0.11	-0.09 ±0.11	-0.06 ±0.04	-0.15 to 0.02	0.56[T]
Upper Body Pushing Power					
5kg MB Chest throw (m)	-0.16 ±0.19	-0.15 ±0.19	-0.01 ±0.07	-0.13 to 0.15	0.05
Grip Strength					
Grip strength left (kg)	-3.61 ±5.30	-6.57 ±7.66	-2.97 ±2.43	-7.98 to 2.04	0.20[T]
Grip strength right (kg)	-7.27 ±6.83	-6.67 ±8.69	-0.60 ±2.85	-5.26 to 6.46	0.13

95% CI (confidence interval) of the difference between measures. Values obtained from subtracting post from pre-testing means.
(S) Training effect towards strongman training, (T) Training effect towards traditional training

8.5 Discussion

The present study is the first to investigate the effects of a strongman training programme versus a traditional training programme on a variety of body composition, muscular function and performance measures. This study provided a unique opportunity to compare two forms of resistance training in athletes whose primary training goal was to improve functional performance (strength, power, speed and change of direction) for the sport of rugby union. While both the strongman and traditional training programmes produced performance benefits, the principle finding in this study was the non-significant between-group differences in body composition and functional performance measures after seven weeks of resistance training. Thus the hypothesis was primarily rejected as both types of training did not offer a significant advantage over the other for improving these outcomes with a short-term training programme.

Small between-group effects to body composition were observed in this study, with the strongman training group having a greater effect in changing muscle mass (ES = 0.44; 1.1% versus -0.02%). Such results may support the findings of Ghigiarelli and colleagues (2013) who suggested that strongman training may be beneficial for improving muscular hypertrophy. Interestingly, small negative effects to body fat mass (kg) (ES = - 0.36) and body fat (%) (ES = - 0.38) were observed in the traditional training group. Previous researchers (Berning, et al., 2007; Keogh, et al., 2010b) have suggested that strongman exercises carry very high physiological demands, which may account for the small differences observed in this study.

It appears that bi-weekly supervised progressive strength training, supplemented with prehabilitation and cardiovascular conditioning, was sufficient stimulus to increase maximal strength in experienced resistance-trained athletes. Similar strength improvements were observed between the strongman and traditional groups for the clean and jerk (8.6% and 10.7%) and military press (9.1% and 7.6%) 1RM strength measures; however between-group effect size analyses indicated small (ES = 0.46: 7.5% versus 2.7%), and moderately greater increases (ES = 0.66: 11.0% versus 5.7%) in squat and deadlift strength, respectively for the traditional than strongman group. Interestingly, a large training effect was observed in the strongman group for the bent over row (ES = 1.10: 13.6% versus 4.3%). The differences in the magnitude of strength improvements between the groups may indicate strength specific adaptations associated with each programme. Interestingly, the magnitude of strength improvements are similar to those reported by Argus and colleagues (2010) for the bench press (11.1%) and box squat (11.3%) in which 33 elite male rugby union players performed five high-volume concurrent strength training sessions per week for 4-weeks. Research has reported enhanced strength improvements with increased frequency of training (Hoffman, Kraemer, Fry, Deschenes, & Kemp, 1990).

The magnitude of traditional 1RM strength improvements seen in the strongman training group were not expected, as the traditional group had a post-strength performance testing advantage as the lifts performed (except the bent over row) were part of the traditional groups programme. Researchers have shown that practice of a specific task gives better ability to transfer strength improvements (Bobbert & Van Soest, 1994). From these results it may be surmised that the strongman exercises utilised in this study have a positive impact on overall strength development.

Improvements in strength and power development can transfer to improved physical capabilities (Stone, Moir, Glaister, & Sanders, 2002). Such results were observed in both training groups with improvements in both upper (seated MB chest press throw = ~0.15 m) and lower body (countermovement vertical jump = ~4 cm; horizontal jump = 3 to 9 cm) power measures. Interestingly, the between-group improvements were very similar for the vertical jump and seated MB chest press throw. The similar magnitude of change in functional performance may be due to specificity of training. Improvements observed in seated MB chest press throw performance may have been attributed to the upper body pushing action of military and axle press exercises. The clean and jerk and log lift, are mechanically similar to the countermovement vertical jump (involving explosive triple extension that occurs at the ankle, knee and hip) and the motor unit firing patterns that are improved during the training of these exercises would likely enhance the firing pattern of these motor units during the countermovement vertical jump as well (Stone, Byrd, Tew, & Wood, 1980). Researchers utilising weightlifting, kettlebell training and vertical jumping exercises have reported significant improvements (1 – 7 %) in vertical jump performance (Otto, et al., 2012; Tricoli, et al., 2005).

An interesting between-group finding in the present study was that the traditional group demonstrated a greater training effect in horizontal jump performance (ES = 0.56) than the strongman training group. The greater moderate improvement in horizontal jump performance (3.8% versus 1.3%) may have been attributed to the greater strength improvements seen in the squat and deadlift which are performed bilaterally.

In contrast, the strongman training group performed heavy sled pulls and farmers walks which involved periods of unilateral and bilateral work and the production of vertical and horizontal propulsive impulses. Interestingly, the strongman training between-group effects were greater for the 5 m (ES = - 0.28; 1.8% faster versus 0.9% faster) and acceleration phase of the 5-0-5 COD test (ES = - 0.33; 1.5% faster versus 3% slower). While the effects are only small, improvements in initial acceleration are important training effects for rugby players as they may provide the player sufficient power to break through tackles and make territorial gains in a match situation. Researchers have reported that heavy sled pulls (33.1 ± 5.9 kg) are a sufficient training stimulus to improve both 5 and 10 m sprint times (Kawamori, et al., In Press) and are commonly used by coaches in strength and conditioning practice (Winwood, et al., In Press-b). The results of this study may support the tenet that specific functional performance adaptation is closely related to the resisted movement patterns associated with the strength and conditioning stimulus. Longer-term training studies could allow better insight into the effectiveness of the heavy sled pull as a conditioning method in improving acceleration performance.

The small differences between the pre-and-post measures for 30 m speed and change of direction times (0.2% to 1.7%) are consistent with other short-term training studies that have examined the effect of two different resistance-training programmes (Hoffman, Cooper, Wendell, & Kang, 2004; Kibele & Behm, 2009; Tricoli, et al., 2005). The results of these studies would indicate that various resistance-training modalities could produce moderate gains in strength and power but only modest changes in speed and COD times. Combinations of high force and high velocity training could result in adaptation occurring at differential parts of the force-velocity curve and therefore have greater impact on athletic performance (Harris, Stone, O'Bryant, Proulx, & Johnson, 2000; Hoffman, et al., 2004; Wilson, Newton, Murphy, & Humphries, 1993; Zafeiridis, et al., 2005).

A surprising finding for the traditional training group in this study was the training effects (~3.4% versus ~1.2%) associated with the 70 kg sled push (5 m, ES = - 0.31; 10m, ES = - 0.33; 15 m, ES = - 0.46). Effects in favour of the traditional style training were not expected as it was thought that the strongman group would improve sled push performance substantially, given that this group had performed the heavy sled pull for seven weeks as part of the strongman training programme. The findings may indicate that the sled pull and sled push elicit different physiological adaptations, or it could be that the strength adaptations associated with the traditional lifts (i.e. squat and deadlift), have better transferability to the horizontal activities (such as the sled push and horizontal jump), a result somewhat counterintuitive (Randell, et al., 2010). Recent research has demonstrated that deep squat (0 - 120^{o} of knee flexion) training (with loads of 5 -10 RM) resulted in greater increases in front thigh muscle CSA, isometric knee extension strength (at 75^{o} and 105^{o} knee extension) and squat jump performance than 12 weeks of shallow squat training (with loads of 5 -10 RM) (Bloomquist, et al., 2013). The strongman exercises seen in this study (e.g. farmers walk and sled pull) are performed with less knee and hip flexion than those seen in the squat and deadlift. Such differences may give insight into the small to moderate effects favouring the traditional group in some of the performance measures seen in the present study.

Previous researchers have reported significant increases in grip strength (5% - 7%) among rugby players after 12 weeks of resistance training (Tong & Mayes, 1995)). Both training groups in this study improved grip strength performance (5 to 13%). It was thought that the strongman training group would show a much greater improvement than the traditional group as the strongman training implements, such as the axle and farmers bars, were thicker than the Olympic bars used in the traditional group. The thicker bars associated with strongman implements have the potential of enhancing grip strength because of the higher degree of difficulty performing exercises while grasping the bar in an area of range of motion where gripping ability is relatively weak (Channel, 1990; Ratamess, Faigenbaum, Mangine, Hoffman, & King, 2007). A limitation to this study was that grip strength was measured with a handgrip strength dynamometer at one angle (which was similar to the thickness of an Olympic bar). Future investigations could test grip strength at different angles, which may give better insight into the grip strength adaptations associated with training implements of varying widths.

A review by Zemke and colleagues (2011) suggested that strongman training programmes could help increase adherence to resistance training programmes. The results of this study found that adherence to training was the same for both groups (98.6%); however the strength and conditioning coaches who oversaw the training in both groups were diligent in monitoring the athletes who participated in this study. Future research may wish to consider giving athletes a self-directed approach to training, which may give a better indication of motivation and programme adherence.

Research on the injury epidemiology of strongman athletes found that strongman implement training carried twice the risk of injury as traditional training methods (Winwood, et al., 2014). While two injuries were reported in this training study, the athlete who had the shoulder injury associated with the strongman programme pulled out of the study. Strength and conditioning coaches who utilise strongman training methods should take into consideration the increased risk of potential injury and follow structured conditioning programmes with a periodised approach. Such an approach would help to ensure appropriate loading strategies for training phases and planned exercise progressions to ensure technical competency with these lifts/events.

The present study sought to collect data from a number of performance tests to gain greater insight into many aspects of muscular function and performance influenced by the training programmes. However, such in-depth analysis is problematic with the issues of statistical significance. The uses of effect sizes were particularly useful for comparing the relative sizes of effects between the different programmes and may better demonstrate ‘practical significance’, particularly if a longer period of training was performed and its effects quantified. Such an approach may be warranted in studies using experienced resistance trained athletes in which increase in performance measures may only be marginal.

In conclusion, this study compared the short term effects of strongman training and traditional training programmes on aspects of muscular function and performance. While the between group effects demonstrated that each programme may have advantages in eliciting specific performance gains, no significant between-group differences were found for the functional performance measures. It seems that when exercises are similar and, load and time under tension are equated, short-term strongman training programmes are as effective as traditional training programmes in improving aspects of muscular function and performance.

8.6 Practical Applications

This study was the first to compare the magnitude of performance changes between a strongman and traditional training programme. From a practical perspective, these findings provide conditioning coaches with the first evidence of the efficacy of strongman-training exercises, which can be used by coaches to improve training practices. From the results of this study it can be concluded that strongman training exercises should be considered as possible alternatives to help supplement traditional training approaches. Strongman exercises could offer variation and help improve athlete motivation. Future training studies should investigate the long-term chronic adaptations associated with each strongman implement and the effectiveness of a combined strongman/traditional programme versus a traditional programme. Such studies would build on the findings of this research and provide practitioners with an evidence base on the performance adaptations associated with strongman implements. This in turn would help improve knowledge regarding the utilisation of strongman exercises in traditional training programmes to further maximise performance enhancements.

8.7 Strongman Training Effects: Technical Note

8.7.1 Matching Loading Parameters for the Strongman Events and Traditional Exercises

Six male strongman athletes (four national and two local level athletes) volunteered to participate in the biomechanical analysis (mean ± SD: age 24.0 ±3.9 yr; stature 181.6 ±9.4 cm; body mass 112.9 ±28.9 kg). Data were collected for each participant over 2 sessions separated by 1 week. Session 1 was performed in the strength and conditioning laboratory and involved 1-repetition maximum (1RM) testing in the squat, deadlift and clean and jerk. Session 2 was performed in the biomechanics laboratory where participants performed repetitions in the squat, deadlift, clean and jerk, farmers walk, log lift and heavy sled pull using the traditional lift (equivalent) loads of 70%1RM. Kinetics were analysed during session 2 only.

A Bertec force plate (Model AM6501, Bertec Corp., Columbus, OH, USA) was used to collect synchronised ground reaction forces at 1000 Hz. Vicon Nexus (Version 1.8.1, Vicon Inc., Denver, CO, USA) was used to process the ground reaction force data. Ground reaction force data were filtered using a fourth order low-pass digital Butterworth filter with a cut-off frequency of 6 Hz.

To calculate and match exercise loading parameters resultant forces were calculated using; square root $(X^2 + Y^2 + Z^2)$

Table 8.4: Calculations of resultant forces

<table>
<tr><th>Deadlift</th><th>Farmers Walk</th></tr>
<tr><td>Total Resultant Forces: $\sqrt{(X^2 + Y^2 + Z^2)}$
= Square root $(0.15^2 + 3.50^2 + 2688.32^2)$
=Square root (0.023 + 12.25 + 7225344.4)
= 2688.00 N
Total lift time = 3.95 seconds</td><td>Total Resultant Forces: $\sqrt{ (X^2 + Y^2 + Z^2)}$
Square root/ $(13.05^2 + -31.50^2 + 2532.72^2)$
=Square root/(182.25 + 22153.35 + 6414670.5)
= 2535.12 N
Average velocity = 1.48 $m{\cdot}s^{-1}$</td></tr>
<tr><td colspan="2">No significant differences were found in the sum of resultant mean forces between the farmers walk (3 - 4 m) and deadlift. Loading was equated by time under tension. One full deadlift repetition (i.e. concentric & eccentric phases) with a 70%1RM load, took 3.95 seconds which equated to a distance of 5.85 m in the farmers walk with a load of 70%1RM deadlift. The initial lift of the farmers lift (0.92 sec) will take 1 m off total distance calculated.
Therefore: 5* Deadlift reps = 28 m of farmers walking with the same given load.</td></tr>
<tr><th>Squat</th><th>Sled Pull</th></tr>
<tr><td>Total Resultant Forces: $\sqrt{(X^2 + Y^2 + Z^2)}$
= Square root $(-3.23^2 + -7.78^2 + 2579.22^2)$
=Square root (10.4 + 60.5 + 6652375.8)
= 2579.2 N
Total lift time = 2.81 seconds</td><td>Total Resultant Forces: $\sqrt{(X^2 + Y^2 + Z^2)}$
Square root/ $(-5.45^2 + 270.82^2 + 1268.95^2)$
=Square root/(29.7 + 73343.5 + 1610234.1)
= 1297.5 N
Average velocity = 1.83 $m{\cdot}s^{-1}$
Step length 0.645 m
Stride length 1.29 m</td></tr>
<tr><td colspan="2">Significant differences were found in the sum of mean resultant forces between the squat and sled pull mean forces. The resultant force for the squat was 2579.2 N which was twice the magnitude of one stride in the sled pull (1297.5 N) (difference between bilateral versus unilateral). Loading was equated by time under tension. One full squat repetition (i.e. concentric & eccentric phases) with a 70%1RM load, took 2.81 seconds which equated to a distance of 5.14 m in the sled pull with a load of 70%1RM squat.
Therefore: 5* squat reps = 25 m of sled pulling with the same given load.</td></tr>
</table>

Note: 0.7 m taken off total sled pull distance to accommodate co-efficient of friction (0.21±0.01μ) (Linthorne & Cooper, 2013).	
Clean and Jerk	Log Lift
Total Resultant Forces: $\sqrt{(X^2 + Y^2 + Z^2)}$ = Square root $(2.36^2 + 2.01^2 + 1921.47^2)$ =Square root (5.57 + 4.04 + 3692046.9) = 1921.5 N Total lift time = 6.20 seconds	Total Resultant Forces: $\sqrt{(X^2 + Y^2 + Z^2)}$ Square root/ $(2.12^2 + 0.86^2 + 1940.26^2)$ =Square root/(4.5 + 0.74 + 3764608.9) = 1940.3 N Total lift time = 7.96 seconds
No significant differences were observed in lift times and sum of resultant forces. Therefore training loads and reps were equal between the clean and jerk and log lift. 5* Clean and Jerks reps = 5* Log Lifts	

CHAPTER 9. GENERAL SUMMARY

9.1 Summary and Discussion

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. This PhD sought to address these potential shortcomings by providing insight into: how strongman implements are utilised in strength and conditioning practice; the stresses that this form of training places on the body; and, the benefits and potential risks associated with strongman implement training. This chapter presents a summary of the main findings for each study presented in this thesis. The practical applications and limitations of each study are emphasised and directions for future research are presented.

9.1.1 Strongman Implements Use in Strength and Conditioning Practice

Practitioners are writing articles and books that advocate the use strongman-type exercises in their athletes' conditioning programmes; however strength and conditioning coaches have little empirical evidence on which to inform the potential inclusion of strongman implement training within their programming practice. This online study which was completed by 220 strength and conditioning coaches aimed to provide some insight into how coaches incorporated strongman implements in their strength and conditioning practice.

- Eighty-eight percent of strength and conditioning coaches utilised strongman implements for performance enhancement in the training of their athletes.
- Eighty-one percent of coaches perceived that strongman implements were good to excellent at eliciting performance gains.
- The sled (pulling/pushing), ropes, kettlebells, tyres, sandbags and farmers walk bars were ranked as the top 6 implements used.
- The three main reasons for strongman implement use were: to transfer gymnasium-based strength gains into more functional strength; add variation; and, place greater demands on the core musculature.

- Coaches ranked anaerobic/metabolic conditioning, explosive strength/power and muscle endurance as the three main physiological reasons for why they used strongman implements in their athlete's training.
- Strongman implements were used both indoors and outdoors (50% each) by coaches and in a variety of ways.
- Coaches reported that the main ways they used strongman implements were in conjunction with traditional exercises in a gym based setting and combined with running conditioning on the field.

The results of this study demonstrate that of the 220 strength and conditioning coaches who completed the survey, most prescribe strongman implements in an integrated fashion to help supplement a variety of strength and conditioning goals. This survey suggests that strongman implements are commonly integrated into strength and conditioning practice despite the paucity of research into the risks and benefits associated with strongman implement training. This study highlighted the need and importance of subsequent studies in this thesis.

9.1.2 Injury Epidemiology Associated with Strongman Implement Training

Injury epidemiology has been examined in power-lifting, weightlifting and bodybuilding; however no injury epidemiology study has been undertaken with strongman athletes. This online study which was completed by 213 strongman athletes sought to provide the first empirical evidence of strongman training and competition injury epidemiology, with sub-analyses by age, body mass and competitive standard also conducted. Major findings included:

- Strongman injury rate (5.5 injuries/1,000 hr training) was higher than the majority of literature for the other three weight training sports of bodybuilding (1.0/1,000 hr training), power-lifting (1 - 5/1,000 hr training) and weightlifting (3 - 4/1,000 hr training).
- The most commonly injured anatomical areas found in the strongmen (in descending order) were lower back, shoulder, bicep and knee. The lower back, shoulder and knee, were injury sites associated with traditional exercises whereas for the strongman events this was the shoulder, bicep and lower back.
- Muscle and tendon strains and tears were the most common types of injury.

- Sixty-six percent of all injuries reported were categorised as acute.
- Ninety-one percent of all injuries to strongman athletes occurred with heavy loads (70 to 90% 1RM).
- Forty-one percent of strongman athletes in this study consulted qualified health professionals for their injuries.
- Twenty percent of injuries were described as having a major effect which required a complete cessation of training for a week or more.
- Thirty-six percent of injured strongman athletes sustained training injuries that occurred early in the training session.
- The >30 y group had almost twice as many major injuries as the ≤30 y group
- The >105 kg group had proportionally less severe and moderate injuries than the ≤105 kg group.

From the survey it was concluded that when the two training approaches were equated by exposure time, strongman implement training resulted in almost twice as many injuries as traditional training. The results of this study provided the first competition and training injury epidemiology data on the sport of strongman and provided insight into the potential risks of strongman implementation.

9.1.3 Comparing the Kinematics and Kinetics of the Farmers Walk with the Deadlift and Unloaded Walk.

Very little peer-reviewed literature has examined the kinematics and kinetics of any strongman events, with none of these studies directly comparing strongman and traditional lifts with the same sample of participants. The purpose of the following three studies was to investigate the kinematics and kinetics of strongman exercises and compare them to biomechanically similar traditional exercises.

The kinetic and kinematic characteristics of the farmers walk (i.e. the lift and walk) were quantified and compared with the two comparable movements, the deadlift and unloaded walk. Significant kinematic and kinetic differences were observed between the lifting (i.e. the farmers lift and deadlift) and walking (farmers walk and unloaded walk) conditions. Major findings included:

- Significantly greater mean vertical force (2893 ± 442 N versus 2679 ± 471 N), mean anterior force (66 ± 23 N versus 42 ± 15 N) and sum of anterior-posterior forces (38 ± 20 N versus 1 ± 4 N) were observed in the farmers lift than the deadlift.
- Deadlift trunk angle was significantly more horizontal (65% more) at lift off and knees passing and significantly more vertical (36% greater) at lift completion compared to the farmers lift.
- Significantly greater ankle dorsiflexion, knee flexion, thigh extension and a more vertical trunk angle were found at knee passing for the farmers lift as opposed to the deadlift.
- The farmers walk demonstrated significantly shorter stride lengths', ground contact times and swing times and significantly higher stride rates than unloaded walk.
- The farmers walk (at 3 – 4 m) was found to have significantly greater dorsiflexion (95.4 ± 2.7 ^{o} vs 105.2 ± 2.4^{o}), knee flexion (154.4 ± 6.5^{o} vs 177.6 ± 6.0^{o}), thigh angle (33.8 ± 5.9^{o} vs 22.8 ± 6.7^{o}), and significantly lesser trunk angle (77.8 ± 3.3^{o} vs 89.6 ± 2.4^{o}) at foot strike than unloaded gait (at 3 – 4 m).
- The shape of the force-time profiles associated with the farmers walk were very similar to unloaded walk.
- A significant loading effect was evident in ground reaction forces, with significantly greater peak and mean forces observed in all three axes during the farmers walk.
- The vertical forces in the farmers walk, were similar to those reported for running (2.8 and 2.3 bodyweights at 4.5 $m \cdot s^{-1}$ and 5.0 $m \cdot s^{-1}$ respectively).
- Peak anterior-propulsive forces and peak posterior braking forces were 1.72 and 1.84 times greater in the farmers walk than unloaded walk respectively.
- Mean braking forces were only 41% greater ($P < 0.05$) in the farmers walk compared to unloaded walk.
- Mean lateral forces in the farmers walk, were not significantly different to the unloaded walk.

The results of this study provided coaches with the first biomechanical description of the farmers walk and provide insight into its kinetic and kinematic determinants. The farmers lift may be a suitable alternative to the deadlift by improving vertical force production while reducing stress to the lumbar spine. The farmers walk could prove to be an efficient mechanical stimulus to enhance various aspects of the gait cycle.

9.1.4 Comparing the Kinematics and Kinetics of the Heavy Sprint Style Sled Pull with the Squat.

The heavy sled pull is the most commonly used strongman implement used by coaches in strength and conditioning practice as a means of performance enhancement, so it was important to obtain data on the heavy sled pull that can provide insight into its effectiveness as a conditioning stimulus. This study quantified the kinetic and kinematic characteristics of the heavy sprint-style sled pull (first stride and stride at 2 – 3 m), and compared the initial start of the sled pull (start of concentric to maximal knee extension) with the back squat. Major findings included:

- The heavy sled pull was found to have significantly greater peak (810 ± 174 N versus 126 ± 73 N) and mean anteroposterior (propulsive) forces (555 ± 107 N versus 43 ± 22 N) than the squat (respectively).
- The squat was found to have significantly greater peak (3503 ± 1286 N versus 1736 ± 463 N) and mean vertical forces (2579 ± 648 N versus 1326 ± 364 N) than the heavy sled pull (respectively).
- Significant differences in the mean ratio of forces were observed between the start of the heavy sled pull (RF = 39.3 ± 5.9 %) and the squat (RF = 0.2 ± 0.3 %).
- Significant differences were observed in absolute trunk angles between the squat (38.8 ± 5.2^o versus 101.4 ± 5.7^o) and start of the heavy sled pull (respectively) at the start of the concentric phase.
- A significantly wider stance width was used for the squat (51.0 ± 10.0 cm) compared to 40.9 ± 9.8 cm for the heavy sled pull.
- Squat and sled pull relative hip (57.0 ± 9.7^o versus 65.6 ± 12.6^o) and ankle angles (81.0 ± 7.3^o versus 76.0 ± 17.3^o) were somewhat similar. However significantly greater knee extension (95.8 ± 18.5^o versus 62.6 ± 6.3^o) was observed at the start of the sled pull.
- Significantly greater range of motion was observed at the hip (106.0 ± 9.3^o versus 51.8 ± 19.0^o) and knee joints (104.8 ± 9.8^o versus 37.4 ± 14.7^o) for the squat compared to the start of the sled pull.
- Relatively few significant differences were apparent between the two sled pull phases (i.e. first stride compared to stride at 2 – 3 m).
- The first stride of sled pull was associated with significantly shorter stride lengths (1.00 ± 0.15 m versus 1.29 ± 0.17 m) and slower average velocities (1.39 ± 0.13 $m \cdot s^{-1}$

versus 1.83 ± 0.22 $m{\cdot}s^{-1}$) than the stride at 2 – 3 m. Significantly greater knee flexion (103 ± 9.4° versus 113.83 ± 5.9°) was also observed at foot strike in the first stride.

- The first stride was associated with significantly greater mean forces in the anterior-posterior (526 ± 162 N versus 271 ± 89 N) and medial-lateral (24 ± 8 N versus -5 ± 22 N) axis than the stride at 2 – 3 m.
- A significantly higher mean ratio of force was associated with the first stride of the heavy sled pull (RF = 37.4 ± 3.8 %) than the stride at 2 – 3 m (RF = 21.7 ± 7.1 %).
- While not significant, a reduction in the magnitude of forces was observed in all three axes for the heavy sled pull at 2 – 3 m compared to the first stride. The reductions in the magnitude of forces were attributed to friction and the force-velocity relationship.

The results of this study provided coaches with the first combined description of the heavy sled pull's kinetic and kinematic characteristics and how these compare to a common lower body exercise, the back squat. The heavy sled pull and squat force profiles show that these exercises are effective conditioning exercises to generate high propulsive and vertical forces (respectively). The heavy sled pull may be an effective conditioning method to improve acceleration performance.

9.1.5 Comparing the Kinematics and Kinetics of the Log Lift with the Clean and Jerk

No studies had investigated the biomechanics of the log lift. This study sought to understand the acute stresses that the log lift imposed on the body and the likely chronic adaptations to this form of training. The kinetic and kinematic characteristics of the log lift were quantified and compared with the clean and jerk. Major findings included:

- Similar ground reaction forces were found in all three axes between the log lift and clean and jerk, except for mean posterior force which was significantly greater in the clean and jerk (↑35%).
- The clean and jerk and log lift were found to have similar bar path kinematics; however a drop in vertical displacement before the second pull in the log lift was clearly evident in the athletes who utilised the squat technique.
- Movements of the bar and log were generally toward the lifter (positive direction) in the first pull, followed by movement away from the lifter during the second pull

(negative direction), and then again toward the lifter (after the point of maximum hip extension associated with the second pull).

- Greater mean horizontal displacements were associated with the clean and jerk in the second pull while greater horizontal displacements were seen in the log press/jerk.
- Peak bar velocity was significantly higher in the clean and jerk in the second pull (16%) and the jerk (14%).
- No significant differences in stance width were found at lift off, top retrieve and lift completion, however significant differences in joint and segmental angles were found throughout the lifting phases, except at lift completion.
- The log lift had significantly greater trunk (7.0 ± 8.0^o versus 20.5 ± 10.1^o) and hip (51.8 ± 6.4^o versus 60.0 ± 5.9^o) flexion angles at lift off than the clean and jerk.
- Significantly greater trunk extension (51.7 ± 14.6^o versus 36.7 ± 5.9^o) was seen in the log lift at the top of the first pull in which the athletes had to pull the log up higher to clear the knees as opposed to the barbell with the clean and jerk.
- Significantly greater dorsiflexion (84.5 ± 6.1^o versus 96.2 ± 3.0^o) and greater knee flexion (99.2 ± 24.8 versus 139.7 ± 11.1) angles were observed in the log lift at the start of the second pull, which reflected the deep squat position associated with this phase of the log lift.
- Significantly greater trunk extension was observed in the log lift during the middle of the second pull (↑18%), top retrieve (↑17%) and bottom of the dip and drive (↑7%).
- Large variances were associated with the knee ($\pm 24^o$), hip ($\pm 28^o$) and trunk angles ($\pm 13^o$) in the log lift at the start of the second pull.
- Trunk and hip range of motion was significantly greater (24^o and 9^o respectively) in the log lift compared to the clean and jerk.

The results of this study provided coaches with the first biomechanical description of the log lift's kinetic and kinematic characteristics and how these compare to the clean and jerk. The log lift and clean and jerk force profiles show that these exercises are effective conditioning exercises that allow the generation of high vertical forces. The log lift may be an effective lifting alternative for coaches who have athletes that are not proficient in the clean and jerk and for athletes who may prefer to press with a neutral grip. Furthermore, in order for athletes to move the log in a vertical direction up the body, greater trunk extension was required to minimise forward horizontal displacement of the log. Coaches who are trying to develop forceful hip extension in their athletes could find the log lift to be an effective training exercise to achieve this.

9.1.6 Evaluating the Effects of Strongman Training versus Traditional Training

Strongman implements are commonly integrated in strength and conditioning practice, however little evidence exists as to the effectiveness of strongman implementation on muscular function and performance. The purpose of this study was to compare the chronic effects of strongman implement training versus traditional training on aspects of muscular function and performance.

From the results of this study it was concluded that a short-term seven week strongman resistance training programme was effective at improving a variety of body composition, muscular function and performance measures, however it was no more effective that the traditional training programme. The principle finding in this study was the non-significant between-group differences in body composition and functional performance measures after seven weeks of resistance training. Major findings included:

- Small between-group effects on body composition were observed with the strongman training group improving muscle mass (ES = 0.44; 1.1% versus -0.02%) more than the traditional group.
- Small negative effects on body fat mass (kg) (ES = - 0.36) and body fat (%) (ES = - 0.38) were observed in the traditional training group compared to the strongman training group.
- Similar strength improvements were observed between the strongman and traditional groups for the clean and jerk (8.6% and 10.7%) and military press (9.1% and 7.6%) 1RM strength measures
- Between-group effect size analyses indicated small (ES = 0.46: 7.5% versus 2.7%), and moderately greater increases (ES = 0.66: 11.0% versus 5.7%) in squat and deadlift strength, respectively for the traditional than strongman group.
- A large training effect was observed for the strongman group compared to traditional group for the 1RM bent over row (ES = 1.10: 13.6% versus 4.3%).
- Similar improvements in both training groups were observed in the seated MB chest press throw (~0.15 m; 3.2 - 3.5%) and the countermovement vertical jump (~4 cm; 6.8 – 6.9%) measures.

- The traditional group demonstrated a greater between group training effect in horizontal jump performance (3.8% versus 1.3%; ES = 0.56) than the strongman training group.
- The strongman training between-group effects were greater for the 5 m (ES = - 0.28; 1.8% faster versus 0.9% faster) and acceleration phase of the 5-0-5 COD test (ES = - 0.33; 1.5% faster versus 3% slower).
- Greater training effects (~3.4% versus ~1.2%) were associated with the traditional training group in the 70 kg sled push (5 m, ES = - 0.31; 10m, ES = - 0.33; 15 m, ES = - 0.46).
- Both training groups in this study improved grip strength performance (5 to 13%).

This study found that when exercises are similar and load and time under tension are equated, short-term strongman training programmes are as effective as traditional training programmes in improving aspects of muscular function and performance.

9.2 Practical Applications

The following recommendations have been developed from the research in this thesis:

1) Strongman implements are useful tools which can be used in a variety of ways for enhancing physiological performance factors in athletes.

2) Strongman training exercises can be considered as possible alternatives to help supplement traditional training approaches.

3) Coaches suggested that strategies such as; monitoring volume and intensity, pairing and grouping athletes and using different sizes and adjustable equipment can be used to overcome difficulties in individualising strongman implement loads for group training sessions.

4) Strongman implementation carries twice the risk to that of traditional training approaches when normalised to exposure time. Therefore strength and conditioning coaches who utilise strongman training methods should follow structured

conditioning programmes with a periodised approach and be especially diligent in requiring sound technique so to minimise the risk of injury during strongman exercise performance.

5) Strategies such as; appropriate warm-up protocols, avoidance of over-training and fatigue, and supplementary training on areas vulnerable to injury may help reduce athlete injury risk when using strongman implements.

6) The farmers lift may have advantages over the conventional deadlift as an effective lifting alternative to generating more anterior-propulsive and vertical force with less apparent stress to the lumbar spine due to the more vertical trunk position.

7) The farmers walk could prove to be an efficient mechanical stimulus to enhance various aspects of the gait cycle as it generates a characteristic gait pattern that has significantly higher vertical, anterior-propulsive and medial lateral forces than unloaded walking.

8) Neuromuscular adaptations such as improvements in the production of anterior-propulsive forces, ankle strength and stability, lower body kinetic chain development, and core strength and stability may result from the inclusion of the farmers walk in resistance training programmes.

9) The heavy sled pull may be an effective conditioning exercise to generate high anterior-posterior propulsive forces as compared to vertically orientated exercises such as the squat.

10) Coaches who wish to utilise the heavy sled pull in conditioning practice should be aware that load, training surface, sled, type and position of harness and length of chain may all influence sled pull kinematics and force-velocity characteristics and hence likely chronic adaptation.

11) The log lift profile may be an effective conditioning exercise that allows the generation of rapid triple extension and high vertical forces.

12) The log lift may be an effective lifting alternative for coaches who have athletes that are not proficient in the clean and jerk and for athletes who may prefer to press with a neutral grip.

13) Short-term strongman training programmes are as effective as traditional training programmes in improving aspects of muscular function and performance when exercises are similar and, load and time under tension are equated.

14) Coaches who wish to utilise strongman implements in strength and conditioning practice should consider individualised exercise prescription with a sports specific approach to elicit optimal neuromuscular adaptations.

9.3 Limitations and Delimitations

Some of the limitations and delimitations of the work in this thesis are acknowledged.

1) The true prevalence of strongman use in strength and conditioning practice may not be as high as our numbers suggest, as coaches who use strongman implements may have been more likely to complete the survey. However, the purpose of this study was to provide the first description of how strength and conditioning coaches are currently using strongman implements in non-strongman athletes' training programmes.

2) The injury rates of the strongman athletes may not be as high as our numbers suggest, as athletes who had more injuries may have been more likely to complete the survey than athletes who didn't get injured.

3) Self-selection bias in the strongman implement and injury epidemiology surveys may be correlated with character traits that affect training practice.

4) Retrospective designs have some limitations for injury epidemiology research due to injury recall. In order to minimise recall bias all strongman athletes referred to their training diaries when completing the survey. The use of a retrospective design was

used as no strongman injury epidemiology studies had been published and of the 12 injury epidemiology studies published in power-lifting, weightlifting and bodybuilding 11 have used the retrospective approach.

5) The percentage of acute injuries presented in the injury epidemiology study must be interpreted with some caution as the present retrospective design lacked medical confirmation. Some injuries may appear acute but could reflect chronic degeneration.

6) Strongman athletes may have been participating in other physical activities that could have potentially contributed to chronic maladaptations to increase the risk of injury during strongman training or competition.

7) The three biomechanical studies were limited as we only had six participants and two were only regional level athletes. Strongman is a relatively new sport in New Zealand and there was a very small pool of participants to choose from in the Auckland area who were actively competing and injury free. However, other biomechanical studies of strongman events have also been published with similar or fewer participants (Keogh, et al., 2010b; Keogh, et al., 2010c; McGill, et al., 2009).

8) The environmental constraints of the laboratory such as surface stiffness and friction may have influenced sled pull and farmers walk gait kinematics and kinetics.

9) The duration of the training study was only 7-weeks which consisted of 14 training sessions. However, the training study reflected the length of a typical off-season macrocycle in the sport of rugby union in which the primary goal was to improve the athletes' strength performance. While a longer training study would have been optimal we only had one macrocycle (mid-October to 20th December) with these athletes before they had to return to signed contracts and club rugby for pre-season training. Previous training studies of shorter durations have been published in the Journal of Strength and Conditioning Research (Argus, et al., 2010; Harrison & Bourke, 2009; Otto, et al., 2012).

10) No test-retest reliability data was obtained for the functional performance tests in the training study. While it would have been optimal to perform multiple trials of these tests at each testing session, logistics and time constraints pertaining to this study did not allow for this to happen. We did however seek to obtain test-retest reliability

scores from previous published studies for the fitness tests utilised in our study. The fitness tests utilised in our study (except the prowler push) were replicated from previous studies who reported ICCs > 0.90.

11) The number of variables collected during the training study posed an issue with statistical significance. To counteract the problem of multiple comparisons and the chance of a false positive, significance was accepted at the $p \leq 0.01$ level as a compromise between increasing risk of both Type I (finding statistical between-group significance where none truly exists) and Type II (finding no statistical between-group significance where one truly exists) errors. For the purposes of this study we placed more emphasis on effect sizes. Effect sizes show the magnitudes of the training effect and may better denote 'practical significance'. Small, moderate and large effect sizes can better demonstrate to coaches the magnitude of the training effects to various stimuli (Hopkins, 2006).

9.4 Directions for Future Research

This thesis has made a substantial original contribution to our knowledge and understanding of strongman implementation in strength and conditioning practice. This thesis has provided insight into how strongman implements are utilised by strength and conditioning coaches, the stresses that this form of training places on the body and the benefits and risks associated with strongman implement training. In the process, several future areas of investigation have arisen.

1) Understanding the effect of strongman implementation on athlete motivation and training adherence is warranted. Such studies would give coaches further insight into the possible benefits of strongman implementation.

2) Future research should involve the use of a prospective cohort or case-controlled design to examine the effect of a variety of independent variables on the injury epidemiology of strongman implement use. Such designs could use a medical examination to increase the validity of the nature of the injury.

3) Studies are needed to investigate the effect of farmers walk velocity and load on anterior-posterior propulsive ground reaction force values. Such research would give insight into how these variables affect ground reaction forces.

4) Future biomechanical studies are needed to determine the effect of sled load, training surface, sled type, type and position of harness and length of chain have on sled pull kinematics and force-velocity characteristics. Such research would give insight into these variables that affect sled pull kinematics and kinetics.

5) Future studies could investigate the training effects of heavy sled pulling on strength, power, speed and body composition measures to give insight into the mechanical and morphological adaptations associated with heavy sled pulling.

6) Future biomechanical studies are needed to investigate the effect of load and log size on lifting kinematics and kinetics. Such research would provide insight into the force-velocity characteristics of log lifting and the kinematic variances associated with performing log lifts with logs of various diameters and loads.

7) Future biomechanical studies on strongman implements are needed to investigate measures such as joint moments and powers as these could give insight into potential adaptations and injury risk.

8) Future training studies should investigate the long-term chronic adaptations associated with each strongman implement and the effectiveness of a combined strongman/traditional programme versus a traditional programme. Such studies would build on the findings of this research and provide practitioners with an evidence base on the performance adaptations associated with strongman implements. This in turn would help improve knowledge regarding the utilisation of strongman exercises in traditional training programmes to further maximise performance enhancements.

9.5 Conclusion

This thesis provides original academic research into strongman implements training and their applications for strength and conditioning practice. The data represented in this thesis can be used by strength and conditioners coaches to help guide programming in order to help maximise the transfer of training to athletic performance and therefore improve training efficiency. The major findings in this thesis were that strongman implements are commonly utilised in strength and conditioning practice and carry twice the risk of injury compared to traditional training approaches. Strongman implements are an appropriate conditioning stimulus to provide acute and chronic stresses that can lead to improvements in muscular function and performance. Coaches who utilise these training methods should follow structured conditioning programmes utilising a periodised approach.

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ABBREVIATIONS AND GLOSSARY

ABBREVIATIONS

1RM	One repetition maximum
2D	Two dimensional
30PST	30 minutes post exercise
%BW	Percentage of body weight
%1RM	Percentage of one repetition maximum
A.D.	After death
A/P	Anterior/posterior
ASCA	Australian Strength and Conditioning Accreditation
ASCC	Accredited Strength and Conditioning Coach
B.C.	Before Christ
BDD	Bottom of dip and drive
BLa	Blood lactate
COD	Change of direction
CSA	Cross sectional area
CSCS	Certified strength and conditioning specialist
CVJ	Counter movement vertical jump
e.d.	Edition
e.g.	Example
EMG	Electromyography
FS	Foot strike
GPT	General preparation phase
GRI	Ground reaction impulse
H	Hypertrophy protocol
H^+	Hydrogen ions

HR	Heart rate
i.e.	That is
KP	Knees passing
KWRS	Keg walk (right shoulder)
LC	Lift completion
LHSC	Left hand suitcase carry
LO	Lift off
MKE	Point of maximal knee extension
MLB	Major league baseball
MM	Muscle mass
MSP	Middle of second pull
N.B.	Nota bene "note well"
NBA	National basketball association
NFL	National football league
NHL	National hockey league
NRL	National rugby league
PCr	Phosphocreatine
PRE	Collected pre exercise
PST	Immediately post exercise
reps	Repetitions
RM	Repetition maximum
ROM	Range of motion
SC	Start of concentric phase
SL	Stone lift
SSP	Start of second pull
SSPT	Sports specific physical training

ST	Strongman only protocol
TF	Tyre flip
TFP	Top of first pull
TO	To off
TR	Top retrieve
UKSCA	United Kingdom Strength and Conditioning Accreditation
USAW	USA Weightlifting Accreditation
XST	Mixed strongman/hypertrophy protocol
VO_2 max	The maximal amount of oxygen a subject can utilise during maximal exercise
YW	Yoke walk

UNITS OF MEASUREMENT

μ	Coefficient of friction
%	Percentage
$1000h^{-1}$	Per one thousand hours
bpm	Beats per minute
CI	Confidence interval
cm	Centimetre
cm^2	Centimetre squared
CV	Coefficient of variation
ES	Effect size
Hr/wk	Hours per week
hrs	Hours
Hz	Hertz
ICC	Intraclass correlation coefficient
kg	Kilogram
$kg.kg^{-1}$	Kilo per kilo of body weight
lb	Pounds
m	Metre
$m{\cdot}s^{-1}$	Metres per second
min	Minute
ml.kg.min-1	Milliliters of oxygen used in one minute per kilo of bodyweight.
mm	Millimetres
$mmol^{-1}$	Millimols
$mmol.L^{-1}$	Millimols per litre
$m{\cdot}s^{-1}$	Metres per second
N	Newtons

^{o}	Degrees
$pg.ml^{-1}$	Picograms per milliliter
r	Correlation coefficient
r^2	Coefficient of determination
SD	Standard deviation
s	Seconds
SEE	Standard error of the estimate
W	Watts
wk	Week
Y	Years

GLOSSARY

Aerobic conditioning	Training focused on improving 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.
Alteres	Latin term for Dumbbells.
Anaerobic endurance	The muscles ability to sustain intense, short duration activity such as weight lifting or sprinting.
Antagonists	A muscle that contracts with and limits the action of the agonist with which it is paired.
Anterior/posterior force	Forces in the Y axis relative to the front and back of the body ($anterior^{+}$/$posterior^{-}$).
Anthropometry	The science of measurement applied to the human body and generally includes measurement of height, weight, and selected body and limb girths.
Biomechanics	The application of the laws of mechanics to biological systems.

Body building	Sport in which athletes use weight training to increase muscle mass.
Body composition	The percentages of fat, bone and muscle in human bodies.
Coefficient of friction	The ratio of the force of friction between two bodies and the force pressing them together.
Determinants	Factors that influence or determine performance.
Diskos	The *diskos* was a word that meant a ‘thing for throwing’ which could have been any object near at hand such as a stone, lump of metal or tree trunk.
Doriflexion	Movement of the foot that flexes the foot in an upward direction.
Epidemiology	The study of patterns of health and illness and associated factors at the population level.
Functional movement	The ability to produce and maintain balance between mobility and stability along the kinetic chain while performing fundamental patterns with accuracy and efficiency.

Functional performance	An athlete's ability to perform sporting activities.
Functional Training	The execution of movements directly related to patterns required for a given sport, with the intent of improving athletic performance.
Girya	Russian term for kettlebells.
Ground reaction impulse	Time over which force was applied.
Hypertrophy training	Training focused on increasing muscle cross sectional area.
Injury	In this thesis injury was defined as any "physical damage to the body that caused the strongman athlete to miss or modify one or more training sessions or miss a competition".
Interrelationships	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.

Lever	In biomechanics, bones act as lever arms, joints act as pivots and muscles provide the effort forces to move loads.
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).
Medial/lateral force	Forces in the X axis relative to the sides of the body (medial^{+}/lateral^{-})
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.
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.
Plantarflexion,	Movement of the foot that flexes the foot downwards.
Power	The rate at which mechanical work is performed (Power = force x distance/time).
Power-lifting	Sport in which athletes attempt to lift the most weight in the squat, bench press and deadlift.
Power training	Training focused on increasing the rate at which force is developed.
Principle of specificity	The more similar a training exercise is to actual physical performance, the greater the probabilities of transfer.
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.
Speed	Distance travelled divide by the time of travel.
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.
Stretch shortening cycle	Stretch reflex initiated by a fast eccentric muscle contraction followed immediately by a fast concentric muscle action.
Strongman competitor	An athlete who competes in strongman competitions.
Strongman Implement	In this thesis a strongman implement was defined as "any non-traditional implement integrated into strength and conditioning practice" (e.g. tractor tyres, farmers walk bars, sleds, sandbags, kegs, steel logs, stones, ropes and kettlebells).
Supplement	An addition designed to complete or to make up for a deficiency.
Synchronisation	The simultaneous or near-simultaneous firing of motor units.
Synergists	Muscle or group of muscles assisting the prime mover.
System Force	A variable developed 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.

Traditional training	In this thesis Traditional training was defined as “standard exercises performed in the gym by regular weight trainers and strength athletes” (e.g. squat, bench press, power clean, etc.).
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).
Weightlifting	Sport in which athletes attempt to lift the most weight in the snatch and clean and jerk.
World’s Strongest Man	Strongman competition in which the world’s best strongman athletes compete for the World’s Strongest Man title.

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APPENDICES

Appendix 1: Abstracts of Descriptive and Experimental Chapters

Chapter 3: HOW COACHES USE STRONGMAN IMPLEMENT IN STRENGTH AND CONDITIONING PRACTICE

Abstract

This article describes how strongman implements, which we defined as “any non-traditional implement integrated into strength and conditioning practice” are currently utilised by coaches to enhance athletic performance. Coaches (mean ±SD 34.0 ±8.2 y old, 9.8 ±6.7 y general strength and conditioning coaching experience) completed a self-reported 4-page survey. The subject group included coaches of amateur (n = 74), semi-professional (n = 38) and professional (n = 108) athletes. Eighty-eight percent (n = 193) of coaches reported using strongman implements in the training of their athletes. Coaches ranked sleds, ropes, kettlebells, tyres, sandbags and farmers walk bars as the top six implements used, and anaerobic/metabolic conditioning, explosive strength/power and muscle endurance as the three main physiological reasons for its use. The strongman implements were typically used in combination with traditional exercises in a gymnasium-based setting. Future research need to evaluate the performance benefits of such training practices in controlled studies.

Keywords: Weight training, resistance training, periodisation, power, variation

Chapter 4: RETROSPECTIVE INJURY EPIDEMIOLOGY OF STRONGMAN ATHLETES

Abstract

This study provides the first empirical evidence of strongman training and competition injury epidemiology. Strongman athletes (n=213) (mean ±SD: 31.7 ±8.8 y, 181.3 ±7.4 cm, 113.0 ±20.3 kg, 12.8 ±8.1 y general resistance training, 4.4 ±3.4 y strongman implement training) completed a self-reported 4-page 1-year retrospective survey of physical injuries that caused a missed or modified training session or competition. Analysis by age (≤ 30 and >30 y), body mass (≤ 105 and >105 kg) and competitive standard (low- and high-level) was conducted. Eighty two percent of strongman athletes reported injuries (1.6 ±1.5 training injuries/lifter/y, 0.4 ±0.7 competition injuries/lifter/y, 5.5 ±6.5 training injuries/1000 hr training). Lower back (24%), shoulder (21%), bicep (11%), knee (11%) and strains and tears of muscle (38%) and tendon (23%) were frequent. The majority of injuries (68%) were acute and were of moderate severity (47%). Strongman athletes utilised self-treatment (54%) or medical professional treatment (41%) for their injuries. There were significantly more competition injuries for the ≤30 y than the >30 y athletes (0.5 ±0.8 vs 0.3 ±0.6; $p = 0.03$) and >105 kg athletes compared with the ≤105 kg athletes (0.5 ±0.8 vs 0.3 ±0.6; $p = 0.014$). Although 54% of injuries resulted from traditional training, strongman athletes were 1.9 times more likely to sustain injury when performing strongman implement training when exposure to type of training was considered. To reduce risk of injury and improve training practices strongman athletes should monitor technique and progressions for exercises that increase risk of lower back, shoulder, bicep and knee musculoskeletal injuries. Clinicians should advise athletes that use of strongman resistance training programs can increase injury risk over traditional exercises.

Keywords: Injuries, strength and conditioning, weight training, implement

What is known about the subject:

No evidence exists as to the injury epidemiology of strongman athletes. Therefore strongman athletes and strength and conditioning specialists have little knowledge of the potential risks of using strongman implements in their training programs.

What this study adds to existing knowledge:

This study provides the first injury epidemiology information for strongman training and competition. The study demonstrates that the potential risks of strongman implement training are greater than traditional training approaches. Strength and conditioning coaches and athletes may be able to improve training practices and reduce injury risk by pre-conditioning areas prone to injury and by monitoring use of strongman implement training. This is especially important given the increased utilisation of such training by sports teams and the fitness industry.

Chapter 5: A BIOMECHANICAL ANALYSIS OF THE FARMERS WALK, AND COMPARISON WITH THE DEADLIFT AND UNLOADED WALK

Abstract

This study compared the biomechanical characteristics of the farmers walk, deadlift and unloaded walk. Six experienced male strongman athletes performed farmers' walks and deadlifts at 70% of their 1RM deadlift. Significant differences ($p < 0.05$) were apparent at knees passing with the farmers lift demonstrating greater trunk extension, thigh angle, knee flexion and ankle dorsiflexion. Significantly greater mean vertical and anterior forces were observed in the farmers lift than deadlift. The farmers walk demonstrated significantly greater peak forces and stride rates and significantly shorter stride lengths, ground contact times, and swing times than unloaded walk. Significantly greater dorsiflexion, knee flexion, thigh angle, and significantly lesser trunk angle at foot strike were also observed in the farmers walk. The farmers lift may be an effective lifting alternative to the deadlift, to generating more anterior-propulsive and vertical force with less stress to the lumbar spine due to the more vertical trunk position.

Keywords: Biomechanics, kinematics; kinetics; strongman; resistance training

Chapter 6: A BIOMECHANICAL ANALYSIS OF THE HEAVY SPRINT-STYLE SLED PULL AND COMPARISON WITH THE BACK SQUAT

Abstract

This study compared the biomechanical characteristics of the heavy sprint-style sled pull and squat. Six experienced male strongman athletes performed sled pulls and squats at 70% of their 1RM squat. Significant kinematic and kinetic differences were observed between the sled pull start and squat at the start of the concentric phase and at maximum knee extension. The first stride of the heavy sled pull demonstrated significantly ($p<0.05$) lower stride lengths and average velocities and a higher mean ratio of force than the stride at 2 – 3 m. The force orientation and magnitude associated with the heavy sprint-style sled pull demonstrates that the heavy sled pull may be an effective conditioning stimulus to generate superior anterior-propulsive forces compared to vertically orientated exercises such as the squat with the same given load. Such adaptations may be beneficial in sports where higher levels of sprint momentum are needed to make and break tackles.

Keywords: Biomechanics, kinematics; kinetics; strongman; resistance training

Chapter 7: A BIOMECHANICAL ANALYSIS OF THE LOG LIFT AND COMPARISON WITH THE OLYMPIC CLEAN AND JERK

Abstract

This study compared the biomechanical characteristics of the log lift and clean and jerk. Six experienced male strongman athletes performed log lifts and clean and jerks at 70% of their 1RM clean and jerk. Significant ($P<0.05$) kinematic differences were observed throughout all the lifting phases, except at lift completion. The log lift demonstrated significantly greater trunk (↑24%) and hip (↑9%) range of motion (°) than the clean and jerk. Significantly greater bar velocities were achieved in the clean and jerk in the second pull (↑16%) and the jerk (↑14%). Similarities existed in ground reaction force data between the lifts except for mean posterior forces which were significantly greater (↑36%) in the clean and jerk. The results demonstrate that the log lift may be an effective conditioning stimulus to teach rapid triple extension while generating similar vertical and anterior-propulsive forces as the clean and jerk with the same given load.

Keywords: Biomechanics, kinematics; kinetics; strongman; resistance training

Chapter 8: STRONGMAN VERSUS TRADITIONAL RESISTANCE TRAINING EFFECTS ON MUSCULAR FUNCTION AND PERFORMANCE

Abstract

Currently, no evidence exists as to the effectiveness of strongman training programs for performance enhancement. This study compared the effects of seven weeks of strongman resistance training versus traditional resistance training on body composition, strength, power, and speed measures. Thirty experienced resistance-trained rugby players were randomly assigned to one of two groups; strongman (n = 15; mean ± SD: age, 23.4 ± 5.6 years; body mass, 91.2 ± 14.8 kg; height, 180.1 ± 6.8 cm) or traditional (n = 15; mean ± SD: age, 22.5 ± 3.4 years; body mass, 93.7 ± 12.3 kg; height, 181.3 ± 5.9 cm). The strongman and traditional training programs required the participants to train twice a week and contained exercises that were matched for biomechanical similarity with equal loading. Participants were assessed for body composition, strength, power, speed and change of direction (COD) performance. Within-group analyses indicated that all performance measures improved with training (0.2% to 7%) in both the strongman and traditional training groups. No significant between-group differences were observed in functional performance measures after 7-weeks of resistance training. Between group differences indicated small positive effects in muscle mass and acceleration performance and large improvements in 1RM bent over row strength associated with strongman compared to traditional training. Small to moderate positive changes in 1RM squat and deadlift strength, horizontal jump, COD turning ability and sled push performance were associated with traditional compared to strongman training. Practitioners now have the first evidence on the efficacy of a strongman training program and it would seem that short term strongman training programs are as effective as traditional resistance training programs in improving aspects of body composition, muscular function and performance.

Key Words: Weight training, functional, transference, variation

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To: John Cronin
From: **Dr Rosemary Godbold** Executive Secretary, AUTEC
Date: 1 March 2012
Subject: Ethics Application Number 12/26 **Strongman training: Application for strength and conditioning practice.**

Dear John

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 13 February 2012 and 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 26 March 2012.

Your ethics application is approved for a period of three years until 1 March 2015.

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/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 1 March 2015;
- 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/ethics. This report is to be submitted either when the approval expires on 1 March 2015 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.

To enable us to provide you with efficient service, we ask that you use the application number and study title in all written and verbal correspondence with us. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902. Alternatively you may contact your AUTEC Faculty Representative (a list with contact details may be found in the Ethics Knowledge Base at http://www.aut.ac.nz/research/research-ethics/ethics).

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

Yours sincerely

Dr Rosemary Godbold

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Paul Winwood p.winwood@yahoo.co.nz, jkeogh@bond.edu.au

AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

A U T E C
S E C R E T A R I A T

5 December 2012

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **12/311 Kinematics and kinetic profiles of three strongman events and three traditional exercises.**

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

Your ethics application has been approved for three years until 5 December 2015.

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 throughhttp://www.aut.ac.nz/research/research-ethics/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 5 December 2015;
- A brief report on the status of the project using form EA3, which is available online throughhttp://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 5 December 2015 or on completion of the project.

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

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

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

All the very best with your research,

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee

Cc: Paul Winwood paul.winwood@boppoly.ac.nz

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

AUTEC SECRETARIAT

25 July 2013

John Cronin
Faculty of Health and Environmental Sciences

Dear John

Re Ethics Application: **13/167 The chronic effects of strongman implement training versus traditional training on aspects of muscular function and performance.**

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

Your ethics application has been approved for three years until 25 July 2016.

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 throughhttp://www.aut.ac.nz/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 25 July 2016;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 25 July 2016 or on completion of the project.

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

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this. If your research is undertaken within a jurisdiction outside New Zealand, you will need to make the arrangements necessary to meet the legal and ethical requirements that apply there.

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

All the very best with your research,

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

Cc: Paul Windwood paul.winwood@boppoly.ac.nz

Appendix 3: Participant Information Letters

Chapter 3 – Exploratory Descriptive Study: Strongman Implement Use in Strength and Conditioning Practice

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Information for Participants

Strongman implement use in strength and conditioning practice

Please note that completion of this survey indicates your consent to participate.

Participant Information Sheet 27/7/12

An Invitation
Hello strength and conditioning coaches. My name is Paul Winwood and I have a passion for resistance training and its application to functional performance. I invite you to take part in an exciting research project. This survey is called 'Strongman implements used in strength and conditioning practice'. This survey will form part of my PhD thesis, which is under the guidance of my supervisors; Professor John Cronin and Associate Professor Justin Keogh. The aim of this study is to help improve our understanding of how strongman implements are used in strength and conditioning practice. The information will benefit strength and conditioning coaches who wish to include this mode of training in the training of their athletes. We would be very grateful to you if you could take the time to fill out this survey. Please know that your participation is entirely voluntary and you will not be disadvantaged by not participating.

What is the purpose of this research?
The purpose of this study is: a) to describe what strongman implements are currently used in strength and conditioning practice; and, b) determine how and why these implements are being used instead of traditional training practices. We will seek to publish a summary of the findings of the study in a scientific journal like the Journal of Strength and Conditioning Research. This research follows on from our recent published research on the sport of strongman: http://www.ncbi.nlm.nih.gov/pubmed/21993033, http://www.ncbi.nlm.nih.gov/pubmed/22233785

How was I identified and why am I being invited to participate in this research?
You have been identified (through the use of LinkedIn, the internet and other strength and conditioning coaches) as a potential participant in this research because you are a strength and conditioning coach.

What will happen in this research?
The on-line survey will take approximately 10 to 15 minutes for you to complete. The questions give you the opportunity to elaborate on your use of strongman implements in your strength and conditioning practice. We would like you to answer as many questions as you can as your knowledge and experience in this field is important to us. The types of questions you will encounter will include; drop down boxes, check boxes, ranking, and open text questions. You are asked to please select or tick which boxes are relevant. For open text box questions please type your answer in.

What will happen to my data?

An academic publication summarising the study findings will be sought and this study will form part of my doctoral thesis. The study data set will only be used for the purpose for which it has been collected. No individual's will be identified and no individual's answers to any questions will be reported. Only summary data will be reported.

What are the benefits?

This study will be most useful for strength and conditioning coaches in terms of how to best incorporate strongman exercises into their athlete's resistance training programmes to help maximise performance-enhancements.

How will my privacy be protected?

You will complete the survey anonymously as only a participant number will be associated with your answers. The researchers will not be able to identify you as a participant.

What are the costs of participating in this research?

There are no costs to you to participate in this research except for your time.

What opportunity do I have to consider this invitation?

The survey link will be active for a period of three months. During this time you are welcome to consider the invitation to take part in this research.

How do I agree to participate in this research?

By completing the questionnaire you have consented to participate in this research project. This also means that you have read and understood all the information contained in the participant information letter and have clarified any details prior to starting the research project.

Will I receive feedback on the results of this research?

If you would like to view the findings of this research please copy and save the URL address below. You will be able to access the results using this URL address in approximately four months time.

www.sprinz.aut.ac.nz/research-results

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John Cronin, john.cronin@aut.ac.nz, Ph 921 9999 ext 7523

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, rosemary.godbold@aut.ac.nz , 921 9999 ext 6902.

Whom do I contact for further information about this research?

Researcher Contact Details: Paul Winwood, Bay of Plenty Polytechnic, School of Applied Sciences, Tauranga, New Zealand, paul.winwood@boppoly.ac.nz

Project Supervisor Contact Details: Professor John Cronin, Sport Performance Research Institute, New Zealand, School of Sport and Recreation, AUT University, Auckland, New Zealand

This research was approved by the Auckland University of Technology Ethics Committee on 21st February 2012, AUTEC Reference number 12/26.

Chapter 4 – Exploratory Descriptive Study: Retrospective Injury Epidemiology of Strongman Competitors

Information for participants
Please note that completion of this survey indicates your consent to participate.
Participant Information sheet 3/04/12

An Invitation
Hello strongman competitors. My name is Paul Winwood and I have competed in bodybuilding and power-lifting, and have a passion for resistance training. I invite you to take part in an exciting research project. The survey is called 'Injury epidemiology of strongman competitors'. This survey will form part of my PhD thesis, which is under the guidance of my supervisors; Professor John Cronin and Associate Professor Justin Keogh (National level U105kg strongman competitor). The aim of this study is to help improve our understanding of the risks and injuries associated with strongman training. The information will benefit strongman athletes and strength and conditioning coaches when prescribing strongman event training to their athletes. We would be very grateful if you could take the time to fill out this survey. Please know that your participation is entirely voluntary and you will not be disadvantaged by not participating.

What is the purpose of this research?
The purpose of this study is: a) to describe the injuries associated with strongman training; and, b) to provide a basis for injury preventive initiatives for strongman implement training. We will seek to publish a summary of the findings of the study in a scientific journal, like the Journal of Strength and Conditioning Research. This research follows on from our recent published research on the sport of strongman: http://www.ncbi.nlm.nih.gov/pubmed/21993033,
http://www.ncbi.nlm.nih.gov/pubmed/22233785

How was I identified and why am I being invited to participate in this research?
You have been identified (through the use of Facebook and the internet) as a potential participant in this research because you are a strongman competitor, who uses a training diary and have at least twelve months current experience in using common strongman exercises like the tyre flip, farmers walk, log press and sled drags in your training. Only strongman competitors who meet these criteria are eligible to participate in this study.

What will happen in this research?
The on-line survey will take approximately 10 to 20 minutes for you to complete. The questions give you the opportunity to elaborate on your use of strongman implements in your strength and conditioning practice and their injury potential. We would like you to answer as many questions as you can as your knowledge and experience in this field is important to us. We want to learn from your experience. The types of questions you will encounter will include; drop down boxes, check boxes, ranking, and open text questions. You are asked to please select or tick which boxes are relevant. For open text box questions please type your answer in.

What will happen to my data?
An academic publication summarising the study findings will be sought and this study will form part of my doctoral thesis. The study data set will only be used for the purpose for which it has been collected. No individual's will be identified and no

individual's answers to any questions will be reported. Only summary data will be reported.

What are the benefits?
This study will be most useful for strongman competitors and strength and conditioning coaches to improve our understanding of the risk factors for injuries and the types of injuries associated with strongman training. Such information will benefit strongman athletes and strength and conditioning coaches when prescribing strongman event training to their athletes.

How will my privacy be protected?
You will complete the survey anonymously as only a participant number will be associated with your answers. The researchers will not be able to identify you as a participant.

What are the costs of participating in this research?
There are no costs to you to participate in this research except for your time.

What opportunity do I have to consider this invitation?
The survey link will be active for a period of three months. During this time you are welcome to consider the invitation to take part in this research.

How do I agree to participate in this research?
By completing the questionnaire you have consented to participate in this research project. This also means that you have read and understood all the information contained in the participant information letter and have clarified any details prior to starting the research project.

Will I receive feedback on the results of this research?
If you would like to view the findings of this research please copy and save the URL address below. You will be able to access the results using this URL address in approximately four months time.
www.sprinz.aut.ac.nz/research-results

What do I do if I have concerns about this research?
Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John Cronin, john.cronin@aut.ac.nz, Ph 921 9999 ext 7523.
Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, rosemary.godbold@aut.ac.nz , 921 9999 ext 6902.

Whom do I contact for further information about this research?
Researcher Contact Details: Paul Winwood, Bay of Plenty Polytechnic, School of Applied Sciences, Tauranga, New Zealand paul.winwood@boppoly.ac.nz
Project Supervisor Contact Details: Professor John Cronin, Sport Performance Research Institute New Zealand, School of Sport and Recreation, AUT University, Auckland, New Zealand

This research was approved by the Auckland University of Technology Ethics Committee on 21st February 2012, AUTEC Reference number 12/26.

Participant Information Sheet

Chapter's 5, 6 & 7 – Cross-sectional descriptive study: An investigation into the kinematics and kinetic profiles of three strongman events and three traditional exercises

24/12/2012

An Invitation

Hello strongman athletes. My name is Paul Winwood and I have a passion for resistance training and its application to functional performance. I invite you to take part in an exciting research project. This study is called "An investigation into the kinematics and kinetic profiles of three strongman events and three traditional exercises ". This study will form part of my PhD thesis, which is under the guidance of my supervisors; Professor John Cronin and Associate Professor Justin Keogh. The aim of this study is to help improve our understanding of the biomechanics of strongman events. The information will benefit strength and conditioning coaches and strongman athletes who include or wish to include this mode of training in the training of their athletes. We would be very grateful to you if you could participate in our study. Please know that your participation is entirely voluntary and you will not be disadvantaged by not participating.

What is the purpose of this research?

The purpose of this study is to examine the kinematics and kinetic parameters of the farmers walk, tyre flip and heavy sprint-style sled pull and the deadlift, power clean and squat. These data will also help to quantify and match the kinetic parameters (i.e. loading) of these exercises for our next study. We will seek to publish a summary of the findings of the study in a scientific journal like the Journal of Strength and Conditioning Research. This research follows on from our recent published research on the sport of strongman:

http://www.ncbi.nlm.nih.gov/pubmed/21993033,

http://www.ncbi.nlm.nih.gov/pubmed/22233785

How was I identified and why am I being invited to participate in this research?

You have been identified as a potential participant in this research because you are a male strongman athlete, 18 to 40 years old, who has a minimum of 3 years resistance training experience and 1 year of strongman implement training experience. You live in Auckland, have an active email address and you have competed in a strongman competition in the previous year.

What will happen in this research?

The study will take place over two days, seven days apart (i.e. consecutive weekends). The first day will involve baseline 1RM testing in the squat, deadlift and powerclean. The second day will involve the lifting of submaximal loads (70%1RM) in the power clean, tyre flip, squat, heavy sled pull, deadlift and farmers walk on force platforms. All lifts will be videoed using the Vicon 3D camera system. An academic publication summarising the study findings will be sought and this study will form part of my doctoral thesis. The study data will only be used for the purpose for which it has been collected. No individual's will be identified. The study data will be kept indefinitely in a secure location at the SPRINZ. There are no plans at this stage for future use of this data. However the data may be of use to future studies including SPRINZ approved student research for degree completions, international collaborative research and other sport, health and fitness related research that would be performed by SPRINZ approved researchers.

What are the discomforts and risks?

Performance testing will carry the amount of discomfort typically experienced in exertion and physical performance, however because you are experienced in resistance training and with strongman events, it will not be outside of your regular experience with resistance training.

How will these discomforts and risks be alleviated?

All risks will be minimised with the use of a comprehensive pre-exercise questionnaire, blood pressure assessment, safety gear (i.e. safety bars in the squat rack) and the use of experienced spotters. Typical 1RM protocols will be followed which provide an optimal warm up and progressive overload. If you have any level of discomfort or you feel you may be at risk you can decline continuation in the study at any time without reprisal.

What are the benefits?

This study will be most useful for sport biomechanist's, athletes and strength and conditioning coaches alike by providing the first kinematic and kinetic profiles of these events. The data will provide evidence of the similarities and differences associated with these exercises and the potential stresses these exercises place on the body's system.

What compensation is available for injury or negligence?

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.

How will my privacy be protected?

Any published material resulting from this research will not identify any individuals; data for participants will be presented as mean values. Researchers will keep information confidential and secure from interception by unauthorised persons. Information obtained will not be used for purposes other than the approved research.

What are the costs of participating in this research?

There are no costs to you to participate in this research except for travelling to and from the AUT/Millennium institute and your time.

What opportunity do I have to consider this invitation?

You have 2-weeks to consider this invitation. During this time you are welcome to email me regarding any questions or concerns you may have.

How do I agree to participate in this research?

If you agree to participate in this research please email me and confirm your participation. You will then be contacted regarding the logistics of the study which will be decided on laboratory and gym availability times. Informed consent forms will be provided before the initial screening and baseline testing commences.

Will I receive feedback on the results of this research?

You can receive a full biomechanical profile of each lift you perform after the full analysis is completed. If you would like this data please let me know either verbally or by email before study commencement.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John Cronin, john.cronin@aut.ac.nz, Ph 921 9999 ext 7523

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Dr Rosemary Godbold, rosemary.godbold@aut.ac.nz, 921 9999 ext 6902.

Whom do I contact for further information about this research?

Researcher Contact Details:

Paul Winwood, Bay of Plenty Polytechnic, School of Applied Sciences, Tauranga, New Zealand, paul.winwood@boppoly.ac.nz, Ph 0800 2677659, ext 6125

Project Supervisor Contact Details:

Professor John Cronin, Sport Performance Research Institute, New Zealand, School of Sport and Recreation, AUT University, Auckland, New Zealand.

Email: john.cronin@aut.ac.nz, Ph 921 9999 ext 7523

Approved by the Auckland University of Technology Ethics Committee on *5/12/12*, AUTEC Reference number *12/311*.

Participant Information Sheet

Chapter 8: The chronic effects of strongman implement training versus traditional training on aspects of muscular function and performance

6/09/2013

An Invitation

Hello, my name is Paul Winwood and I have a passion for resistance training and its application to functional performance. I invite you to take part in an exciting research project. This study is called “an investigation into the chronic effects of strongman implements training versus traditional training on aspects of muscular function and performance “. This study will form part of my PhD thesis, which is under the guidance of my supervisors; Professor John Cronin and Associate Professor Justin Keogh. The aim of this study is to help improve our understanding of the chronic adaptations associated with strongman implement training. The information will benefit strength and conditioning coaches who wish to include this mode of training in the training of their athletes. We would be very grateful to you if you could particpate in our study. Please know that your participation is entirely voluntary and you will not be disadvantaged by not participating.

What is the purpose of this research?

The purpose of this study is to examine the chronic effects (i.e. long term adaptations) associated with 8-weeks of two forms of resistance training (i.e. traditional and strongman implement training). These data will provide the first empirical evidence of the effectiveness of strongman implement training compared to traditional training approaches. We will seek to publish a summary of the findings of the study in a scientific journal like the Journal of Strength and Conditioning Research. This research follows on from our recent published research on the sport of strongman:

http://www.ncbi.nlm.nih.gov/pubmed/21993033,

http://www.ncbi.nlm.nih.gov/pubmed/22233785

How was I identified and why am I being invited to participate in this research?

You have been identified as a potential participant in this research because you are a male rugby athlete, 18 to 35 years old, who has a minimum of 1 year resistance training experience and some strongman implement training experience. You live in the Tauranga region and are part of a 1st division or semi-professional rugby team.

What will happen in this research?

The study will take place over a 9 week period. The first week will involve baseline 1RM testing (squat, deadlift, clean and jerk and military press) and functional performance testing (30m sprint, MB chest press throw, vertical jump height, horizontal jump, grip strength, and 505-agility). A 7-week training period will then follow in which you will perform a 1 hour resistance training protocol (traditional or strongman) twice a week. In the week after the 7 week training intervention you will repeat the functional performance testing you did prior to the study.

An academic publication summarising the study findings will be sought and this study will form part of my doctoral thesis. The study data will only be used for the purpose for which it has been collected. No individual's will be identified. The study data will be kept indefinitely in a secure location at the SPRINZ. There are no plans at this stage for future use of this data. However the data may be of use to future studies including SPRINZ approved student research for degree completions, international collaborative research and other sport, health and fitness related research that would be performed by SPRINZ approved researchers.

What are the discomforts and risks?

Performance testing will carry the amount of discomfort typically experienced in exertion and physical performance, however because you are experienced in resistance training and with contact sports, it will not be outside of your regular experience with resistance training.

How will these discomforts and risks be alleviated?

All risks will be minimised with the use of a comprehensive pre-exercise questionnaire, blood pressure assessment, safety gear (i.e. safety bars in the squat rack) and the use of experienced spotters. Typical 1RM protocols will be followed which provide an optimal warm up and progressive overload. If you have any level of discomfort or you feel you may be at risk you can decline continuation in the study at any time without reprisal.

What are the benefits?

This study will be most useful for athletes and strength and conditioning coaches alike by providing the first evidence base on the effectiveness of strongman implement training compared to traditional training approaches. The data will provide evidence of the performance adaptations associated with these exercises.

What compensation is available for injury or negligence?

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.

How will my privacy be protected?

Any published material resulting from this research will not identify any individuals; data for participants will be presented as mean values. Researchers will keep information confidential and secure from interception by unauthorised persons. Information obtained will not be used for purposes other than the approved research.

What are the costs of participating in this research?

There are no costs to you to participate in this research except for travelling to and from the training facility and your time. You will need to dedicate 2 hours a week for the training sessions over an 7-week period as well as the time for pre and post intervention testing (approximately 4 hours).

What opportunity do I have to consider this invitation?

You have 4-weeks to consider this invitation. During this time you are welcome to email me regarding any questions or concerns you may have.

How do I agree to participate in this research?

If you agree to participate in this research please email me and confirm your participation. You will then be contacted regarding the logistics of the study which will be decided on gym availability times. Informed consent forms will be provided before the initial screening and baseline testing commences.

Exclusion Criteria

In order to keep you safe you must be able perform all the lifts with adequate technical competency. If you cannot perform the lifts correctly you will be excluded from the study. You will however be able to stay on and help the researchers in a research assistant role if you wish. This role will include assisting strength and conditioning coaches and participants with gym equipment, filling of water bottles and athlete motivation.

Will I receive feedback on the results of this research?

If you would like to view the findings of this research please copy and save the URL address below. You will be able to access the results using this URL address in approximately six months time.

www.sprinz.aut.ac.nz/research-results

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Professor John Cronin, john.cronin@aut.ac.nz, Ph 921 9999 ext 7523

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, *Kate O'Connor*, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher Contact Details:

Paul Winwood, Bay of Plenty Polytechnic, School of Applied Sciences, Tauranga, New Zealand, paul.winwood@boppoly.ac.nz, Ph 0800 2677659, ext 6125

Project Supervisor Contact Details:

Professor John Cronin, Sport Performance Research Institute, New Zealand, School of Sport and Recreation, AUT University, Auckland, New Zealand.

Email: john.cronin@aut.ac.nz, Ph 921 9999 ext 7523

Approved by the Auckland University of Technology Ethics Committee on *25/7/2013*, AUTEC Reference number *13/167*

Appendix 4: Informed Consent Forms

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***An investigation into the kinematics and kinetic profiles of three strongman events and three traditional exercises***

Project Supervisor: Professor John Cronin, john.cronin@aut.ac.nz

Researcher: Paul Winwood, paul.winwood@boppoly.ac.nz

○ I have read and understood the information provided about this research project in the Information Sheet dated 04/12/2012
○ 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 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.
○ I am not suffering from any illness, high blood pressure, or injury that impairs my physical performance to perform resistance training.
○ 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 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 agree to take part in this research.
○ I consent to the indefinate storage of my data.
○ I wish to receive a copy of the report from the research (please tick one):
Yes○ No○

Participants signature:
....

Participants name:
....

Participants Contact Details (if appropriate):
....
....
....
....

Date:

Approved by the Auckland University of Technology Ethics Committee on 4/12/12 AUTEC Reference number 12/311

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

Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: ***The chronic effects of strongman implement training versus traditional training on aspects of muscular function and performance***

Project Supervisor: Professor John Cronin, john.cronin@aut.ac.nz
Researcher: Paul Winwood, paul.winwood@boppoly.ac.nz

○ I have read and understood the information provided about this research project in the Information Sheet dated 06/09/2013
○ 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 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.
○ I am not suffering from any illness, high blood pressure, or injury that impairs my physical performance to perform resistance training.
○ 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 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 agree to take part in this research.
○ I consent to the indefinite storage of my data.
○ I consent to be contacted in future in the case of a follow up study
○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature:
....

Participant's name:
....

Participants Contact Details:
……………………………………………………………………………………..
……………………………………………………………………………………..
……………………………………………………………………………………..
……………………………………………………………………………………..

Date:

Approved by the Auckland University of Technology Ethics Committee on 05/07/13
AUTEC Reference number 13/167

Appendix 5: Questionnaires

Strongman Implement Use in Strength and Conditioning Practice Questionnaire (Chapter 3)

Section 1: Demographics

1) What is your gender?

2) What is your age? (years)

3) What country do you work in as a strength and conditioning coach?

4) How many years of strength and conditioning coaching experience do you have?

5) What is the main sport you work with?

( ) American Football

( ) Rugby League

( ) Rugby Union

( ) Other

6) Can you please specify?

____

7) Do you work with athletes that are amateur, semi-professional or professional?

( ) Amateur

( ) Semi-professional

( ) Professional

8) What is the highest level of education you have completed?

( ) Some high school

( ) High school/GED

( ) Some college

( ) Associate's degree

( ) Bachelor's degree

( ) Master's degree

( ) Doctorate degree

( ) Medical degree

( ) Trade or other technical school degree

9) What vocational qualifications do you have? (e.g. CSCS)

____

Section 2: Resistance Training and Periodisation

INSTRUCTIONS

For the purposes of this study, the term "strongman implement" can be any non-traditional implement integrated into your strength and conditioning practice.

Common strongman implements used in training include; tractor tyres, farmers walk bars, pushing/pulling sleds, sandbags, kegs, steel logs, stones, ropes, chains and blocks/tools used for grip exercises.

Traditional training refers to traditional exercises such as the squat, bench press and power clean.

Please refer to your training calendar/periodised plan when answering the questions.

Please remember that these questions relate to your strength and conditioning practice with your athletes and not your own personal training.

10) Do you use some form of periodisation in your athletes training?

Note: 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.

( ) Yes

( ) No

11) Do you or have you used strongman implements in your strength and conditioning practice?

( ) Yes

( ) No

12) How many resistance training sessions (on average) do you generally run with your team each week? (This includes any resistance training method i.e. bodyweight, traditional (e.g. squat and bench press) and strongman implement training (e.g. farmers walk and tyre flip)

Question Range: 1 to 7 or more

13) How long (on average) would each of your teams resistance training session be (to the nearest 15 minutes)? (This includes any resistance training method i.e. bodyweight, traditional (e.g. squat and bench press) and strongman implement training (e.g. farmers walk and tyre flip)

14) How often (on average) do you use strongman implements in your athletes training?

( ) Never
( ) once a month
( ) twice a month
( ) three times a month
( ) once a week
( ) twice a week
( ) three times a week
( ) more than three times a week

15) Can you please briefly explain why you dont use strongman implements in your strength and conditioning practice?

16) How long (on average) would each of your teams training session be in which you use strongman implements? (to the nearest 15 minutes)

( ) <15min
( ) 15min
( ) 30min
( ) 45min

( ) 60min

( ) 75min

( ) 90min

( ) >90min

( ) I dont use strongman implements in my athletes training

Section 3: Periodisation

17) Where do you use strongman implements in your yearly/periodised training plan? (Tick which boxes are relevant)

[ ] General Preparation Phase

[ ] Specific Preparation Phase

[ ] Competitive Phase

18) What is the main phase in which you use strongman implements in your yearly/periodised training plan? (Tick the one box that is most relevant)

( ) General Preparation Phase

( ) Specific Preparation Phase

( ) Competitive Phase

19) Please rank (i.e. 1 main reason, 2 secondary reason etc) the main physiological responses you are trying to elicit when you use strongman implements in your athletes yearly/periodised training plan. Note: If you only use strongman implements for a couple of reasons, just rank the reasons that are applicable to you.

_______Anaerobic/Metabolic conditioning

_______Muscular Endurance

_______Hypertrophy

_______Maximal Strength

_______Explosive Strength/Power

Section 4: Strongman Implement Use

20) Typically, do your athletes train indoors or outdoors with strongman implements?

( ) Indoors

( ) Outdoors

21) How many strongman implements/events (on average) would you integrate into your athletes resistance training sessions?

Question range: 1 to 7 or more

22) Rank (in order of use; top being most commonly used to bottom being least used) the strongman implements that you use in the conditioning of your athletes (Note: If you dont use all the implements just rank the ones you do use).

________Farmers Walk bars

________Steel Logs

________Sand Bags

________Sled Pulling/Pushing

________Yoke/Duck walk implements

________Objects/tools for heavy carrying

________Ropes

________Kettle bells

________Tyres

________Stones

________Kegs

________Axles

________Blocks/tools for grip exercises

________Crucifix/ tools for holds

________Chains

________Cars/frames for heavy deadlifts

________Other/s

If you chose 'other/s' can you please specify?

____

23) This question will be extremely beneficial for all strength and conditioning coaches into how strongman implements can be utilised in strength and conditioning

practice.

Using your top 3 strongman exercises you chose in the previous question (if you didnt choose 3 please just use the ones you did choose) please state your main reason for using this implement, the average reps, distance or time, sets, loads (kg's or as a % of 1RM), rest periods between sets/exercise and movement velocities (e.g. slow, moderate or fast/explosively) you typically use for each strongman exercise. Please start from the most commonly used and write in the strongman exercise you are referring to.

Strongman Exercise 1?: ____

Reason for use?: ____

Reps, Distance or Time?: ____

Sets?

Question range: 1 to 20

Loads? (i.e. as a % of 1RM, or Kg's):

____

Rest between sets?

Question range: 15 sec to >6min

Movement speed the exercise is performed at?

( ) Slow

( ) Moderate

( ) Fast/Explosively

Question repeated x2

24) Please rank in order of importance (with 1 being most important to 6 being least important) why you use strongman exercises. Note: If you don't use them for all the reasons stated just rank the reasons you do use.

I use strongman implements in my athletes training because they....

_______Add variation to my athletes training programmes

_______Help transfer gym based strength gains into more functional strength

________Are more specific to my sport than traditional gym based exercises
________Give greater adherence to my training programmes
________Play a role in injury prevention
________Place greater demand on the body's core musculature than other resistance training approaches.

25) Please briefly describe what you think are some other advantages of using strongman implements compared with traditional training methods in the training of your athletes.

26) Please rank (from 1 to 5) the way you use strongman implements in your athletes training (1 being most commonly used to 5 being hardly ever or don't use). Note: If you dont use them for all the reasons stated just rank the reasons you do use.
I use....
________Strongman implements combined with traditional exercises in a gym based setting
________Strongman implements only in a gym based setting
________Strongman implements only on the field
________Strongman implements combined with running conditioning on the field
________Strongman implements and traditional training combined with running conditioning on the field

27) Are there any other reasons you use strongman implements in the training of your athletes that were not previously mentioned?
( ) Yes
( ) No

28) Could you please specify your other reasons for using strongman implement training with your athletes?

29) In your experience of strongman implement use, how have you found this mode of training in regard to injury risk compared to traditional modes of training? (Choose the one box that is most applicable)

( ) Strongman implement training puts my athletes at greater risk of injury than traditional training

( ) Strongman implement training carries the same risks as traditional training

( ) Strongman implement training carries less risks than traditional training

30) Have you found any difficulty in acquiring strongman implements?

( ) Yes

( ) No

31) Have you found any difficulty in storing strongman implements?

( ) Yes

( ) No

32) One possible disadvantage of using strongman implements compared to traditional methods is the inability to personalise loads when dealing with large groups of athletes (i.e. smaller and weaker athletes have to work much harder than their stronger counterparts). What strategies do you use to overcome this problem?

33) Briefly describe what you think are some disadvantages of using strongman implements compared with traditional training methods in the training of your athletes.

34) Currently, there are no training studies that give any scientific evidence of the effectiveness of strongman implement training. How effective has strongman implement training been for increasing your athletes' performance/s?

( ) Excellent

( ) Good

( ) Okay

( ) Not very good

( ) No good at all

35) Please elaborate on your answer.

36) Is there anything else you would like to add?

Thank You!

Thank you for your participation in this survey. Your response is very important to us.

We appreciate the time and effort you have put in to complete this survey.

Regards

Paul Winwood

Retrospective Injury Epidemiology of Strongman Competitors Questionnaire (Chapter 4)

Section 1: Demographics

1) What is your gender?

2) What is your age? (years)

3) What is your height (cm)?

4) What is your body mass (kg)?

5) What is your country of origin?

6) How many years of general resistance training experience do you have?

7) How many years of strongman implement training experience do you have?

8) How many years have you been competing in the sport of strongman?

9) What is the highest level of strongman competition you have competed at?

Section 2: Training

Please refer to the whole year of training (i.e. all of 2011) and please use your training diary when answering the questions in this survey.

10) How many resistance training sessions (on average) did you generally perform each week in the past year? Questions 10 to 13 refer to all aspects of your yearly training phases i.e. general preparation phase, specific preparation phase, competition phase, and post competition. Please note that resistance training refers to all types of training with any resistance i.e. traditional (e.g. squat and bench press) and strongman implement training (e.g. farmers walk and tyre flip)

11) How long (on average) would each of your resistance training session be to the nearest 15 minutes?

12) How many training sessions (on average) did you generally perform each week using strongman implements?

13) What percentage (on average) of your overall training consists of strongman implement training? Think about % of sets per resistance training session over a week.

14) Rank the type of strongman events that you use (1 being most commonly performed to 6 being least performed). If you don't perform all types of events just rank the ones you do use.

_______Carries and Walks (e.g. Farmers, Yoke, Duck, Conan's wheel, shield, kegs, and frame)
_______Drags and Pulls (e.g. Truck, sleds, arm over arm, ropes and chains)
_______Presses (e.g. Log, Viking, axle and dumbbells)
_______Lifts (e.g. Stone, Tyre flip, Safe, kettle bells and car deadlift or squat)
_______Grip exercises (e.g. block, hand and tools).
_______Holds (e.g. crucifix)

15) Rank what strongman implements you commonly incorporate into your training (Top being most commonly performed to bottom being least performed). If you don't perform all types of events just put in the ones you do use.

_______Farmers Walk bars
_______Steel Logs
_______Sand Bags
_______Sled Pulling/Pushing
_______Yoke walk implements
_______Conans wheel/tools for heavy carrying
_______Ropes
_______Kettle bells
_______Tyres
_______Stones
_______Kegs
_______Axles
_______Blocks/tools for grip exercises
_______Crucifix/ tools for holds
_______Chains
_______Cars/frames
_______Duck walk implements
_______Viking press implements

Section 3: Previous Injury

For the purposes of this study, the term "injury" will be defined as any physical damage to a body part that caused you to miss or modify one or more training sessions or competitions. Please keep this definition in mind when answering the questions. You will need to refer to the past year of training (i.e. all of 2011) when answering these questions. Please refer to your training diary when answering the questions as this will help to eliminate recall bias.

16) How many training injuries (i.e. injuries that occured during training sessions) did you suffer from in the LAST YEAR that affected your training ? (Note: This question refers to training only and not competition injuries which the next question covers).

Answer Range: None to >10

17) How many competition injuries (i.e. injuries that occured during competition) did you suffer from in the LAST YEAR that affected your training? (Note: This question refers to competition only and not training injuries which the previous question covered).

Answer Range: None to >10

18) In regard to any injury/s you recieved in the last year. Were your injury/injuries a direct result of training with strongman implements (i.e. farmers walk and tyre flip) or traditional exercises (i.e. squat and bench press), both or are you unsure?

[ ] Strongman Implements

[ ] Traditional Exercises

[ ] Strongman implements and traditional exercises

[ ] Unsure

[ ] I had no injuries

19) What traditional exercises or strongman events were you performing when you suffered the injury? Please state what part of the body was injured, the injury type and what type of exercise/event you were performing e.g. front squat, stone lift, tricep extension. Please also answer the other questions pertinent to that injury.

Injury site 1?

( ) Shoulder

( ) Neck

( ) Upper back
( ) Elbow
( ) Hip/buttock
( ) Knee
( ) Groin
( ) Chest
( ) Lower back
( ) Tricep
( ) Quadricep
( ) Bicep
( ) Hamstring

Injury Type?

( ) Unsure
( ) Bruise
( ) Laceration/Cut
( ) Muscle Strain/Tear
( ) Tendon Strain/Tear
( ) Ligament Sprain/Tear
( ) Cartilage Damage
( ) Bone Fracture/break
( ) Other

What traditional exercise or strongman event were you performing that resulted in the injury? ____

What type of surface or terrain were you performing the exercise on?

( ) Grass
( ) Concrete
( ) Asphalt
( ) Carpet
( ) Wooden floor
( ) Astroturf (artificial grass)
( ) Other

What time of day (approximately) did the injury occur?

Range: 01:00 to 24:00

Approximate Load (as a % of 1RM) you were doing?

Range: 5 to 100

Did the injury occur in your; General preparation phase, Specific preparation phase, Pre-competition phase, during competition or post competition?

( ) General preparation phase
( ) Specific preparation phase
( ) Pre-competition phase
( ) During competition
( ) Post competition

At which part of the training session or competition did the injury occur (i.e. early, mid or late)?

( ) Early in the training session
( ) Middle of the training session
( ) Late in the training session
( ) Early in the competition
( ) Middle of the competition
( ) Late in the competition

What do you think was the reason for your injury? i.e. poor technique, faulty equipment etc: ____

How did this injury affect your training?
( ) Small alteration (i.e. changed your performance of an exercise)
( ) Large alteration (i.e. stopped you from performing an exercise)

( ) Stopped (i.e. stopped your training completely)

Did this injury occur suddenly (just happened) or did it gradually become worse over time?

( ) Suddenly (i.e. No warning, injury was felt at a particular time)
( ) Gradually (i.e. Soreness or stiffness became gradually worse over time)

Is this the first time you have had this injury or is it a repeated injury (i.e. multiple back sprain)?

( ) First time
( ) Repeated

What type of treatment was used to manage the injury?

( ) None
( ) Self-administered (eg. ice, liniment, strapping, etc)
( ) Medical (e.g. doctor, physiotherapist, chiropractor, etc)

What safety equipment were you wearing when the injury occured?

[ ] None
[ ] Wrist straps
[ ] Elbow wraps
[ ] Knee wraps
[ ] Weight belt
[ ] Lifting suit

20) Have you had a 2nd injury in the past year?

( ) yes
( ) no (Question 19 repeated until answer was no)

Section 4: Additional information

38) Based on your experiences training with using strongman implements; how have you found this mode of training in regard to injury risk compared to traditional modes of training?

( ) Strongman implement training carries a greater risk of injury than traditional training
( ) Strongman implement training carries the same risk of injury as traditional training
( ) Strongman implement training carries less risk of injury than traditional training
Please explain your answer.

____

____

39) Please rank what you believe is the most dangerous strongman event to the least dangerous event in terms of injury risk.

_______Farmers Walk
_______Log clean and press
_______Heavy Sled Pulling/Pushing
_______Yoke Walk
_______Duck walk
_______Conans wheel
_______Tyre flip
_______Stone lift
_______Keg toss
_______Chain drag
_______Cars/frames for heavy deadlifts
_______Cars/frames for heavy carrying
_______Other
If you chose other, please specify ____
40) Is there anything that you wish to add?

____

Thank You! Your response is very important to us.

Sports Injury Questionnaire for the Study titled

Instructions

For the purposes of this study, the term "injury" will be defined as any physical damage to a body part that caused you to miss or modify one or more training sessions or competitions. Please keep this definition in mind when answering the questions.

Name: **Age:** **Gender:**
Date:

Normal weight Class:

Address:

Phone: **(H)**
(W)

Fax: **Email:**

SECTION 1: Training

Q1.1 How many years have you been training with weights?

Q1.2 How many years have you been competing in power-lifting competitions?

Q1.3 In your current age and weight class, based on your total, are you eligible to compete at International level?

Q1.4 How many training sessions did you generally perform each week?

Q1.5 How long (on average) would each training session be (to the nearest 15 minutes)?

Q1.6 For your main exercises (squat, bench press and deadlift) what percentage of your training would be in following repetition?

1-4 reps ☐ **5-8 reps** ☐

9-12 reps ☐ **More than 12 reps** ☐

SECTION 2: Previous Injury

Q2.1 How many injuries did you suffer from in the **LAST YEAR** that affected your training?

Q2.2 To what parts of the body were these injuries to?

Shoulder/neck	☐	Chest	☐
Upper back	☐	Lower back	☐
Elbow	☐	Arm	☐
Hip/buttock	☐	Thigh	☐
Knee	☐	Other	☐

Q2.3 If so, how did this injury (injuries) affect your training?

Injury 1: Site

Small Alteration	☐	Changed your performance of an exercise
Large Alteration	☐	Stopped you from performing an exercise
Stopped	☐	Stopped your training completely

Injury 2: Site

Small Alteration	☐	Changed your performance of an exercise
Large Alteration	☐	Stopped you from performing an exercise
Stopped	☐	Stopped your training completely

Injury 3: Site

Small Alteration	☐	Changed your performance of an exercise
Large Alteration	☐	Stopped you from performing an exercise
Stopped	☐	Stopped your training completely

Injury 4: Site

Small Alteration	☐	Changed your performance of an exercise
Large Alteration	☐	Stopped you from performing an exercise
Stopped	☐	Stopped your training completely

Q3.4 Did this injury occur suddenly (just happened) or did it gradually become worse over time?

Injury 1 Site:
Suddenly ☐ No warning, injury was felt at a particular time
Gradually ☐ Soreness or stiffness became gradually worse over time

Injury 2 Site:
Suddenly ☐ No warning, injury was felt at a particular time
Gradually ☐ Soreness or stiffness became gradually worse over time

Injury 3 Site:
Suddenly ☐ No warning, injury was felt at a particular time
Gradually ☐ Soreness or stiffness became gradually worse over time

Injury 4 Site:
Suddenly ☐ No warning, injury was felt at a particular time
Gradually ☐ Soreness or stiffness became gradually worse over time

Q3.5 What exercises were you performing when you suffered the injury? Include similar exercises to the squat, bench press and deadlift here as well. For example:

"Squats" would also include front squats, Smith machine squats, etc,
"Bench presses" would also include DB bench press, incline/decline bench press etc "Deadlifts" would also include sumo, straight leg, Romanian, good-mornings etc
"Other-gym" include other exercises e.g. lat pulldown, tricep extension, leg curl etc
"Non-gym" means not associated with gym training e.g. running, work, car crash etc

Injury 1 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other-gym** ☐
Non-gym ☐ **Unknown** ☐

Injury 2 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other-gym** ☐
Non-gym ☐ **Unknown** ☐

Injury 3 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other-gym** ☐
Non-gym ☐ **Unknown** ☐

Injury 4 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other-gym** ☐
Non-gym ☐ **Unknown** ☐

Q3.6 What exercises must be modified/discontinued as a result of the injury?

Injury 1 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other** ☐

Injury 2 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other** ☐

Injury 3 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other** ☐

Injury 4 Site
Squats ☐ **Bench press** ☐
Deadlifts ☐ **Other** ☐

Q3.8 What type of treatment was used to manage the injury?

Injury 1 Site
None
☐
Self-administered (eg. ice, liniment, strapping, etc)
☐
Medical (eg. doctor, physiotherapist, chiropractor, etc)
☐

Injury 2 Site
None
☐
Self-administered (eg. ice, liniment, strapping, etc)
☐
Medical (eg. doctor, physiotherapist, chiropractor, etc)
☐

Injury 3 Site
None
☐
Self-administered (eg. ice, liniment, strapping, etc)
☐
Medical (eg. doctor, physiotherapist, chiropractor, etc)
☐

Injury 4 Site
None
☐
Self-administered (eg. ice, liniment, strapping, etc)
☐
Medical (eg. doctor, physiotherapist, chiropractor, etc)
☐

Appendix 6: Injury Epidemiology of Female Strongman Athletes

Results

Demographics and training characteristics

Injury data were collected from nine female strongman athletes, which included all training sessions and competitions for the previous year. Demographics, and training data of the subjects are presented in Table A-1. The average resistance training experience and strongman implement training experience amongst all female lifters was 10.4 ± 9.2 yrs and 3.8 ± 2.6 yrs respectively. Subjects reported that they spent 5.0 ± 1.8 hours per week resistance training with 1.9 ± 1.1 of those hours training with strongman implements.

Table A-1: Demographics and training characteristics (mean ±SD) for female strongman athletes.

	All Lifters (n = 9)
Demographics	
Age (y)	32.3 ± 6.4
Height (cm)	167.9 ± 7.1
Body mass (kg)	85.8 ± 18.5
Training	
Resistance training experience (y)	10.4 ± 9.2
Strongman implement training experience (y)	3.8 ± 2.6
Amount of strongman implement training ($h.wk^{-1}$)	1.9 ± 1.1
Amount of total resistance training ($h.wk^{-1}$)	5.0 ± 1.8

Injury rate, onset, severity and treatment

Table A-2 indicated that subjects obtained a training injury rate per year of 1.1 ± 0.8, which equated to 4.8 ± 4.2 training injuries per 1000 hours of training. Subjects had an average competition injury rate of 0.1 ± 0.3 per year. Over two-thirds of the injuries reported by the injured lifters were acute injuries (i.e. happened suddenly). The majority of injuries were injuries that had occurred for the first time (70%). Half the injuries were considered moderate, which stopped the subject from performing an exercise. The majority of the lifters (50%) sought help from medical professionals for their injuries.

Table A-2: The number (and percentage) of total occurrences for injury rate, onset, occurrence, severity and treatment reported by injured strongman athletes (n = 7).

	All injured athletes (n = 7)
Rate	
Training injuries/athlete/y	1.1 ± 0.8
Competition injuries/athlete/y (n=1)	0.1 ± 0.3
Training injuries/1,000 hr	4.8 ± 4.2
Onset	
Acute	7 (70.0%)
Chronic	3 (30.0%)
Occurrence	
First Time	7 (70.0%)
Repeated	3 (30.0%)
Severity	
Mild	5 (50/0%)
Moderate	5 (50.0%)
Major	0 (0.0%)
Treatment	
None	2 (20.0%)
Self	3 (30.0%)
Medical	5(50.0%)

Injury nature (body site and type)

The most common sites of injury were lower back (30%), shoulder (30%), which accounted for 60% of the injuries reported (see Table A-3). Muscle strains and tears were the most common reported injury for lower back (30%) and attributed to 60% of all types of injuries reported by the female subjects. Tendon strains and tears were the most commonly reported injury for the shoulder (30%).

Table A-3: The number (and percentage) of total injury occurrences (n = 10) for body site and injury nature for the combined forms of resistance training reported by 7 injured female strongman athletes.

Injury site	Muscle strain/tear	Tendon strain/tear	Total
Lower back	3 (30%)		3 (30%)
Shoulder		3 (30%)	3 (30%)
Bicep	1 (10%)		1 (10%)
Abdomen	1 (10%)		1 (10%)
Elbow		1 (10%)	1 (10%)
Ankle/Foot	1 (10%)		1 (10%)
Total	6 (60%)	4 (40%)	10 (100%)

Exercises and injury sites

Traditional exercises accounted for 60% of the injuries reported in the study (see Table A-4). The most common sites of injury for the traditional exercises were lower back (30%), and shoulder (30%). while the sites of injury for the strongman events were elbow (10%), bicep (10%), calf (10%) and abdomen (10%).

The most common causative traditional exercises were squat (20%) and overhead press (20%) which accounted for 40% of all injuries reported by the subjects. The most common causative strongman events were Yoke walk (10%), tyre flip (10%), grip events (10%), and other (10%) which accounted for 40% of the injuries reported in this study. Of the traditional exercises the deadlift and squat produced the most lower back injuries (10% and 20% respectively) while the overhead press produced the most shoulder injuries (20%).

Table A-4: The number (and percentage) of injury sites (n = 10) by exercises for traditional and strongman events reported by injured strongman athletes (n = 7).

Event/Exercises	Shoulder	Elbow	Lower back	Bicep	Calf	Abdomen	Total
Traditional							
Deadlift			1 (10%)				1 (10%)
Squats			2 (20%)				2 (20%)
Overhead press	2 (20%)						2 (20%)
Pull ups	1 (10%)						1 (10%)
Other						1 (10%)	1 (10%)
Strongman							
Yoke walk					1 (10%)		1 (10%)
Tyre flip				1 (10%)			1 (10%)
Grip events		1 (10%)					1 (10%)
Total	3 (30%)	1 (10%)	3 (30%)	1 (10%)	1 (10%)	1 (10%)	10 (100%)

Key: Other: Not stated

Risk factors for injury (load, time, technique)

The subjects were asked a range of questions relating to injury including; time of day, load (as a % of 1RM), and injury occurrence. The highest reported injury incidence was at 12pm (20%) with 80% of injuries reported to occur between 12pm and 8pm.The results showed that the majority of injuries (30%) occurred with a loading of 70%1RM (one repetition maximum) with 90% of all injuries occurring with heavy loads (70 to 100% of 1RM). The majority of injuries (50%) occurred in the subjects general preparation phase. Subjects were asked which part of the training session or competition the injury occurred. The majority of training injuries (50%) occurred in the middle of the training session.

Table A-5: The number (and percentage) of injury sites (n = 268) by exercises for traditional and strongman events reported by injured male strongman athletes (n = 174).

	Shoulder	Neck	Upper back	Elbow	Hip/butt	Knee	Groin	Chest	Lower back	Quads	Bicep	Hamstrings	Other	Total
Traditional Exercises														
Deadlift		1 (0.4%)	5 (1.9%)	1 (0.4%)	4 (1.5%)	1 (0.4%)	1 (0.4%)	1 (0.4%)	25 (9.3%)	1 (0.4%)	1 (0.4%)	6 (2.2%)		47 (17.5%)
Squats	4 (1.5%)	1 (0.4%)	1 (0.4%)		2 (0.7%)	11 (4.1%)			12 (4.5%)	5 (1.9%)	3 (1.1%)	3 (1.1%)		42 (15.7%)
Overhead press	13 (4.9%)	2 (0.7%)	1 (0.4%)	6 (2.2%)					1 (0.4%)		1 (0.4%)			24 (9.0%)
Bench press	11 (4.1%)							5 (1.9%)						16 (6.0%)
Glute ham raise							1 (0.4%)					1 (0.4%)		2 (0.7%)
Ab wheel roll-out			1 (0.4%)						1 (0.4%)					2 (0.7%)
Other	2 (0.7%)		2 (0.7%)	2 (0.7%)		1 (0.4%)			2 (0.7%)		2 (0.7%)	1 (0.4%)		12 (4.5%)
Traditional total	30 (11.1%)	4 (1.5%)	10 (3.7%)	9 (3.4%)	6 (2.2%)	13 (4.9%)	2 (0.7%)	6 (2.2%)	41 (15.3%)	6 (2.2%)	7 (2.6%)	11 (4.1%)		145 (54.1%)
Strongman Events														
Stone work	1 (0.4%)		1 (0.4%)			3 (1.1%)	2 (0.7%)		7 (2.6%)		8 (3.0%)		2 (0.7%)	24 (9.0%)
Yoke walk	1 (0.4%)	2 (0.7%)	3 (1.1%)		3 (1.1%)	2 (0.7%)			5 (1.9%)	1 (0.4%)	1 (0.4%)		3 (1.1%)	21 (7.8%)
Tyre flip	1 (0.4%)			1 (0.4%)		1 (0.4%)			1 (0.4%)	1 (0.4%)	10 (3.7%)		1 (0.4%)	16 (6.0%)

Farmers walk	3 (1.1%)		1 (0.4%)	1 (0.4%)		1 (0.4%)	1 (0.4%)		3 (1.1%)	1 (0.4%)		1 (0.4%)		12 (4.5%)
Axle clean/work	1 (0.4%)			3 (1.1%)	1 (0.4%)	1 (0.4%)	1 (0.4%)		1 (0.4%)		2 (0.7%)		1 (0.4%)	11 (4.1%)
Log lift/press	7 (2.6%)					1 (0.4%)		1 (0.4%)	2 (0.7%)					11 (4.1%)
Circus dumbbell	6 (2.2%)													6 (2.2%)
Car dead lifts	2 (0.7%)			1 (0.4%)					2 (0.7%)					5 (1.9%)
Sled work						2 (0.7%)						1 (0.4%)		3 (1.1%)
Truck pull						1 (0.4%)							1 (0.4%)	2 (0.7%)
Keg/barrel loading						1 (0.4%)					1 (0.4%)			2 (0.7%)
Sandbags	1 (0.4%)		1 (0.4%)											2 (0.7%)
Weight over bar/distance	1 (0.4%)							1 (0.4%)						2 (0.7%)
Other	2 (0.7%)								1 (0.4%)		1 (0.4%)	1 (0.4%)	1 (0.4%)	4 (1.5%)
Strongman total	26 (9.7%)	2 (0.7%)	6 (2.2%)	6 (2.2%)	4 (1.5%)	13 (4.9%)	4 (1.5%)	2 (0.7%)	22 (8.2%)	3 (1.1%)	23 (8.6%)	3 (1.1%)	9 (3.4%)	123 (45.9%)
Total	56 (20.9%)	6 (2.2%)	16 (6.0%)	15 (5.6%)	10 (3.7%)	26 (9.7%)	6 (2.2%)	8 (3.0%)	63 (23.5%)	9 (3.4%)	30 (11.2%)	14 (5.2%)	9 (3.4%)	268 (100%)

Key: The results are expressed in two ways with the top value being the total number of occurrences and the bottom value (in parentheses) the percentage of total occurrence.
Other (causative activity and site for traditional exercises) consists of: weighted chins and skull crushers (elbow), press ups and rotator work (shoulder), shrugs and rack pull (upper back), power clean and bent over row (bicep), hyperextension and good morning (lower back), leg press (knee).
Other (causative activity and site for strongman events) consists of kettle bell carry and wrestling (shoulder), frame carry (lower back), power stairs (hamstrings), Duck walk (other), and palms up for hold bicep).