LIMB COMPRESSION DOES NOT ALTER THE FORCES GENERATED DURING THE VERTICAL JUMP

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Submitted to the faculty of the University Graduate School
in partial fulfillment of the requirements
for the degree
Master of Sciences
in the School of Heath, Physical Education, and Recreation, Department of Kinesiology,
Indiana University
December, 2009

Acknowledgements

I would like to personally thank my thesis committee for the time, effort, and support put in on this project. Without their direction it would been impossible to finish. I would also like to thank my family and friends for their sacrifice and support during this process.

ABSTRACT

TITLE: LIMB COMPRESSION DOES NOT ALTER THE FORCES GENERATED DURING THE VERTICAL JUMP

PURPOSE: The purpose of this study was to identify potential differences in impulse force generated during the vertical jump while wearing commercially available compression shorts as compared to non-compressive, loose fitting gym shorts.

HYPOTHESIS: Leg muscle compression will produce no significant difference in muscle performance variables generated during a standard vertical jump test when compared to no compression.

METHODS: Twenty five physically active males between the ages of 18 and 30 were recruited for this study. Each subject was asked to wear 4 types of shorts: non-compressive gym shorts (representing a control), regular fitting compression shorts (by manufacturer standard), undersized compression shorts (one size smaller than manufacturer standard), and oversized compression shorts (one size larger than manufacturer standard). The subjects were familiarized with the testing procedures and then completed the three randomized conditions on the same day. The performance tests consisted of 3 sets of 10 countermovement vertical jumps performed upon a force platform. The dependent measures included: velocity at takeoff (Vto; m·s), fatigability across jumps (Vf ; m·s) and surface electromyography (EMG; volts).The maximal impulse generated was taken from the highest curve out of the 10 jumps and average power was determined across the 10 jumps in each condition. The individual compression values were then determined in each condition for each subject with the use of a custom made compression quantification device. Results: There were no significant differences (P>.05) in Vto, Vf, and EMG across compression levels. Conclusions: The compression garments produce no significant change in the forces generated during the vertical jump.

Definitions of Terms

Cardiac Output: the amount of blood pumped by the heart per unit of time.

Mean Arterial Pressure (MAP): the average amount of pressure in the vascular system during circulation.

Intramuscular pressure: the pressure developed inside a muscle after a contraction during the relaxation phase.

Muscle oscillation: the amount of vibration in a specific muscle during a particular movement.

Velocity at Take-off (Vto): Peak height = Velocity at peak multiplied by time to peak minus one-half gravity multiplied by time to peak squared.

Electromyography (EMG): The process of recording myoelectric signals produced by various muscles.

Squat Jump: Vertical jump initiated from a squat position (thighs parallel to the floor with 90 degree bend at knee) with hands on waist at all times.

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Chapter One

Introduction

In competition, having a competitive edge is essential. Manufacturers develop products that potentially provide a competitive edge, but for a price. Compression garments were developed to provide a competitive edge to athletes. However, is there any scientific evidence that compression garments actually provide any competitive benefit? If they do, what are the physiological mechanisms associated with the claimed performance gains?

Statement of the Problem

There is a lack of scientific evidence supporting the use of compression garments for performance enhancement. This study was designed to determine whether or not limb compression has any influence on the velocity at takeoff and muscle activity, generated by the thighs, during a vertical jump. Limb compression influence can be determined by measuring the velocity of the vertical jump at takeoff as this determines the height of the vertical jump. Determining the velocity at takeoff makes it possible to identify variables, such as maximum power output, average power output, and fatigability (decrease in average power output) across several jumps. Measuring the velocity at takeoff with electromyography (EMG) could potentially determine any neural changes, in the thigh, that occur during the jump. Conducting the vertical jump test while under limb compression also makes it possible to determine the influence of limb compression on vertical jump performance.

Purpose of the Study

The purpose of the study was to test whether or not a significant difference in the subject's ability to perform a vertical jump test occurred under normal and experimental conditions. Normal conditions consisted of the subject wearing a control garment, while experimental conditions consisted of the subject wearing the following: undersized, regular fitting, and oversized compression shorts. The compression levels were defined as undersized compression (one size smaller than the proper manufacturer sizing), regular fitting (proper manufacturer sizing), and oversized compression (one size larger than the proper manufacturer sizing). The following hypotheses tested for potential significant differences:

1.) Null Hypothesis: There is no significant difference in the forces generated during a vertical jump, between control conditions (control garment) and experimental conditions (undersized, regular fitting, and oversized compression shorts).

   a. There is no significant difference in electromyography, during a vertical jump, between control conditions (control garment) and experimental conditions (undersized, regular fitting, and oversized compression shorts).

2.) Alternative hypothesis: There is a significant difference in the forces generated during a vertical jump, between control conditions (control garment) and experimental conditions (undersized, regular fitting, and oversized compression shorts).

  a. There is no significant difference in electromyography, during a vertical jump, between control conditions (control garment) and experimental conditions (undersized, regular fitting, and oversized compression shorts).

Need for the Study

Limited scientific evidence suggests that compression garments provide performance gains to the wearer. A large push toward users wearing compression shorts was made in the garment industry when Kraemer (1996) published a study about compression short use. Kraemer (1996) showed no significant influence on maximal jump power, but there was an increased ability to maintain power production over repeated jumps. Kraemer (1996) noted that the compression garments were designed for long-term wear, not to induce high levels of compression (Kraemer et al., 1996). Contradictory to Kraemer's (1996) study, Shim (1999) showed significant changes in maximal-effort jumping height, which was believed to be due to mechanically assisting the athletes by the stretching of the suit during the vertical jump.

Power lifters have used compression suits for years. Benefits exist from the use of tightly bound wraps around the joints, such as the knees, as this potentially enhances force production (Harman and Frykman, 1990). Limited scientific evidence leads to a need for further research on limb compression and performance when wearing compression garments.

Not only do powerlifters use limb compression, but it has also been used for years in the medical setting to help with vascular insufficiencies, such as vascular reflux and edema (Sarin et al., 1992; Bouten et al., 2001). However, high levels of limb compression are not always beneficial. Large amounts of compression, leading to ischemia, have resulted in tissue damage and decreased muscle function (Hargens , 1989; Bouten et al., 2001; Gawlitta et al., 2007).

The lure of enhanced performance for athletes entices individuals to overlook the negative and focus on the potential positive effects. Further research is needed to determine if limb compression aids the user's performance, to distinguish the amount of limb compression seen in the compression garments, and to compare the results with previous research. Pairing new and old research will allow for the determination of the mechanisms associated with limb compression and the effect on the performance of the user.

Limitations of the Study

The limitations to this study are as follows: (1) using only male subjects, in Bloomington, Indiana; (2) subjects were asked to complete a vertical jump test, as opposed to other anaerobic performance tests; (3) four different conditions: control (loose fitting garment) and experimental (undersized, regular fitting, and oversized compression shorts); and (4) a small sample size of 25 participants.

The purpose of this study was to examine the influence of limb compression on the forces generated during a vertical jump. To determine if limb compression had an influence, the hypothesis that the control conditions, of no compression, would not be different than the experimental conditions (compression), was tested.

To validate the purpose of this test, it was necessary to investigate potential mechanisms of limb compression by comparing previous research.

Chapter Two

Review of Literature

Introduction

In order to validate if compression has any influence on limb compression, it was necessary to investigate potential mechanisms of limb compression by comparing previous research on limb compression. Limb compression has been used for many years in a clinical setting. The uses in the clinical setting have been investigated and established as compression therapy.

Compression Therapy

Compression therapy has been an accepted form of treatment since the days of Hippocrates. Compression therapy remains heavily debated (Adams, 1849) due to the risks associated with increased pressures, such as compartment syndrome and a potential decrease in blood flow. Compression therapy can be defined as the use of external compression in the treatment of swollen extremities (Partsch, 1991). Its mechanisms are not fully understood. 'Compartment syndrome,' is a common issue with compression and results in increased tissue pressures (Matsen et al., 1979). Compartment syndrome can be defined as elevated tissue pressures from swelling within the osteofascial compartments of a limb (Matsen, Krugmire, & King, 1979). Increased tissue pressures and excessively tight bandages result in a hesitation to use compression therapy. Investigations on excessively tight bandages (Volkmann, 1967) and compartment syndrome have been shown to compromise tissue function (Matsen, 1975). Compression therapy has been shown to help with disorders such as vascular insufficiencies and edema by reducing venous reflux and peripheral swelling (Aston, 1966). Investigations have been conducted to elucidate the effects of external compression on potential mechanisms, but the results indicated inconsistencies in compression levels on physiological mechanisms (Table 1).

Compression and Physiology

Early investigators researched the influence of limb compression and blood haemodynamics (Aston, 1966; Miller et al., 1978; Matsen et al., 1979; Sarin, Scurr, & Smith, 1992). Aston (1966) investigated the influence of air splints on blood flow, while Miller (1978) looked into the effects of tourniquets on blood flow. Air splints resulted in a marked reduction in blood flow when inflated to 40 mmHg (Aston; 1966). The reduced blood flow was increased when the compressed limb was elevated above the heart. Miller's (1978) investigated the use of tourniquets on blood flow, which resulted in ischemic conditions. Held for long periods, ischemic conditions (occluded blood flow) could result in cell damage. Matsen et al. (1978) also investigated the influence of limb compression on blood flow. Blood flow was monitored when external compression of 80 mmHg was applied to the hind limb of New Zealand rabbits. The results indicated progressive changes in blood flow with applied pressures of 80 mmHg to the hind limb (Matsen et al., 1979). Contrary to reports suggesting decreases in blood flow, Ghandi, Palmer, & Schraibman (1984) and Lawrence (1980) reported increases in blood flow with the use of commercial grade compression gear that elicited an undisclosed amount of compression. The conflicting results may be due to methodological differences, such as increased blood flow with exercise and undisclosed amounts of compression, across studies.

External pressure has also been shown to have an influence on venous reflux (reversed blood flow) and blood vessel diameter (Sarin, Scurr, & Smith, 1992). Results indicated that at 40 mmHg, an absence of venous reflux and a reduction in vessel diameter were present. These results suggest that external compression, at 40 mmHg, reversed blood flow is impeded and that vessel size is reduced. These investigations demonstrated that using limb compression can result in a marked reduction in blood flow, an absence of venous reflux, and a reduction of vessel diameter.

Just as blood flow, the partial pressure of oxygen, in the blood and tissue (PO_2), has been shown to decrease with the use of limb compression. Matsen (1979) and Miller (1978, 1979) investigated the influence of limb compression on PO_2. The results indicated that tissue and blood PO_2 , measured directly via catheters, progressively decrease with an increase in limb compression. For the decreases in PO_2, the applied pressures ranged from 0 mmHg to 100 mmHg. The direct measurement used to determine PO_2 all resulted in its reduction with the use of limb compression.

As PO_2 was shown to decrease (Miller et al., 1978; Matsen et al., 1979; Matsen, Krugmire, & King, 1979), the partial pressure of carbon dioxide (PCO_2) has been shown to increase with the use of limb compression (Miller et al., 1978; Matsen, Krugmire, & King, 1979). PCO_2 was tested under compression ranging from 0 mmHg to 80 mmHg in pressure, and under ischemia. Standards for commercial compression garments do not exist while typical medical grade compression ranges from 0 to 45 mmHg. Results indicated progressive increases in tissue PCO_2 with increasing pressures. Blood PCO_2 was also shown to increase as a function of time in an ischemic environment (Miller et al., 1978). Investigations suggest that the use of limb compression, over time, may cause an increase in blood PCO_2.

Lymphatic flow has been shown to increase with the use of limb compression (Miller & Seale, 1981). Miller and Seale (1981) investigated the influence of compressive forces on the terminal lymphatic function in mongrel dogs. The compressive pressure was increased in increments of 15 mmHg until lymph clearance disappeared, which was around 60 mmHg. This indicated a complete closure of the terminal lymphatic function. The increased pressure resulted in lymph flow away from the tissue until 60 mmHg was applied (Miller & Seale, 1981). This research suggests that the use of limb compression up to 60 mmHg is beneficial in the removal of lymph.

Limb compression, 80 mmHg, has been shown to affect both nerve and muscle conduction velocity (Matsen et al., 1979; Hargens et al., 1989). Compartment syndrome has been associated with changes in myoneural tissue function in humans (Hargens et al., 1989). To determine myoneural changes, the applied pressure ranged from low compression, 0 mmHg, to high compression, 80 mmHg, (Matsen et al., 1979; Hargens et al., 1989). Results indicated that changes in conduction velocities did not occur until around 80 mmHg, and were not evident until 65 to 75 minutes after the start of the compression. As mentioned previously, limb compression could lead to ischemic conditions, which result in cell damage (Miller et al., 1978). To investigate cell damage with ischemic conditions, muscle samples were collected and compressed under incremental strains (Bouten et al., 2001). The applied strains ranged from 10 to 40% gross construct strain, and the muscle samples were assessed for structure and cellular damage. Bouten (2001) suggested that muscle cells increase in cell damage while under compression, as compared with the uncompressed controls (Bouten et al., 2001). Cell damage has also been assessed by tissue deformation and hypoxia (low oxygen levels) (Gawlitta et al., 2007). Both investigations showed that compressed samples resulted in further cell damage compared to the uncompressed controls (Bouten et al., 2001; Gawlitta et al., 2007). Research suggests that the use of external compression could lead to tissue deformation, which may lead to increased cellular damage.

Reports have suggested many changes in physiology with the use of limb compression. Attempts have been made to better understand these changes and identify potential mechanisms to how the changes occur. Compression therapy can elicit unwanted and potentially dangerous side effects. Further research is necessary to further our understanding of the mechanisms associated with its use.

The previously mentioned research suggests that certain physiological variables change with the use of limb compression. A physiological model may be produced from this information to show what can be expected from compression use (Table 1). It is important to note that the results change according to the amount of compression used. No set standard of compression has been determined to allow for direct comparisons between studies. A number of these studies were conducted on animals, which can complicate the results further, due to differences in anatomy and physiology. Previous research can be used to understand limb compression better, and to attempt to identify all physiological mechanisms associated with its use. Table 1 summarizes the physiological mechanisms associated with compression.

Table 1. Physiological mechanisms of compression.

Mechanism	**Effect**	**Compression Level**	**References**
Blood Flow	↓	Incremental increase at 40-80 mmHg	3,24,29
PO_2	↓	Incremental increase at 0-100 mmHg	24,25,26
PCO_2	↑	Incremental increase at 0-100 mmHg	24,25,26
Lymph Flow	↑	Incremental at 0 until full collapse @ 60 mmHg	26
Nerve Conduction Velocity	↓	Function of time under pressure (0-80 mmHg)	15
Muscle Conduction Velocity	↓	Function of time under pressure (0-80 mmHg)	15
Motor Function	↓	Function of time under pressure (0-80 mmHg)	15
Vein Diameter	↓	Begins at 40 mmHg; fully occluded at 100 mmHg	29
Cell Damage*	↑	Function of time and pressure*	8,13

* Function of global compression at 20 and 40% for 22 hr (Gawlitta et al., 2007).

Compression, Exercise Physiology, and Performance

Compression therapy has progressed from compartment syndrome (Matsen et al., 1979), air splints and stocking studies (Aston, 1966), and has recently taken on a new form. Manufacturers began producing compression clothing and other equipment for the purposes of enhancing performance around nineteen fold. The benefits of compression therapy or tissue deformation are still debated, but its use is gaining popularity in the sporting community. How will exercise have an effect on the physiological mechanisms described previously? With the progression of compression equipment, is there any scientific evidence suggesting compression garments aid in performance?

Previous reports suggested wearing compression clothing increases skin temperature at the compression sites (Duffield & Portus; 2007). Subjects wore full body compression while any significant differences in skin temperature occurred between control and experimental conditions. Wearing the full body compression suit, eliciting an undisclosed amount of compression, resulted in a significant increase in skin temperature (28.5±0.8 – 30.3±0.8°C) during exercise. This increase in skin temperature found by Duffield and Portus (2007) was supported by an earlier investigation conducted by Doan et al. (2003). The results indicated that the use of full body compression suits and custom compression shorts increased skin temperature with exercise.

The influence of limb compression on blood pressure and heart rate has been investigated by previous studies (Kraemer et al., 2000; Bell & White; 2005; Ali, Caine, & Snow; 2007; Duffield & Portus; 2007). Compression levels ranged from 5.2 mmHg to ischemic conditions (100+ mmHg) during exercise. The results indicated that blood pressure increased (~25.6 ±14.9 mmHg) while heart rate remained unchanged (171±9.5 - 175±10 bpm).

Creatine kinase and blood lacate have been investigated after exercise where the limbs were compressed, in attempts to quantify muscle damage (Berry et al., 1987; Berry et al., 1990; Duffield & Portus; 2007). Creatine kinase was monitored after exercise in cricket players wearing full body compression suits with undisclosed amount of compression (Duffield & Portus, 2007). Each subject was required to complete an exercise protocol designed to elicit changes in creatine kinase (Duffield & Portus; 2007). The results indicated a significant increase (1266±120 - 1050±166μl) in 24-hour post-exercise creatine kinase levels in those cricketers not wearing the suit compared to the experimental condition, who did not wear the suit. This result suggests that the use of full body compression suits helps increase the recovery of the individual wearing the full body compression suit. Blood lactate has found to be significantly lowered with the use of an unreported amount of limb compression (Berry et al., 1987). However, Duffield and Portus (2007) found that lactate levels increased (8.2 ±2.4 -9±2.4 mmol) with the use of compression garments. The lower lactate levels in Berry (1990) study resulted from the inhibition of lactate removal from muscular beds caused by the wearing of compression garments. This suggests that the use of limb compression does not decrease blood lactate levels post exercise.

The increased prevalence of compression clothing in the running world lead to investigations on the influence of limb compression on maximum oxygen uptake (VO_2 max) and fatigue (time to failure) (Berry & McMurray, 1987; Joyce, Bernier & Perrin; 1994; Kraemer et al., 1998; Bernhardt & Anderson, 2005). The investigations into maximum VO_2 required each subject to complete a running protocol and compared the controls with no compression, with the experimental condition of unmeasured compression (Berry & McMurrary, 1987; Bernhardt & Anderson, 2005). Fatigue or time to failure, was tested with each subject undergoing repetitive force production (Joyce, Bernier, & Perrin; 1994; Kraemer et al., 1998).

The results suggested no significant differences in both maximum VO_2 and fatigue, and that the use of limb compression for increases in VO_2 max and decreases in fatigue is unwarranted.

Increased interest in potential performance increases has lead to investigations researching limb compression and balance, agility, speed, and range of motion (Doan et al., 2003; Bernhardt & Anderson, 2005; Ali, Caine, & Snow; 2007; Duffield & Portus; 2007). Subjects were exposed to undisclosed amounts of compression while completing testing protocols. The experimental results from the subjects wearing compression garments were compared to those of control subjects wearing no compression equipment. Results indicated no significant differences in balance, agility, and speed (Bernhardt & Anderson, 2005; Ali, Caine, & Snow, 2007; Duffield & Portus, 2007), but resulted in significant decreases in range of motion (Doan et al., 2003; Bernhardt & Anderson, 2005).

Limb compression has been suggested to help with anaerobic performance (Harman & Frykman, 1990). Studies investigated the influence of limb compression on the performances for vertical jump, one repetition maximum, average power output, and total work capacity (Joyce, Bernier, & Perrin, 1994; Kraemer et al., 1996; Kraemer et al., 2000; Doan et al., 2003; Bernhardt & Anderson, 2005). Each subject was required to complete one test out of the following: a vertical jump test (Kramer et al., 2000; Doan et al., 2003); one repetition maximum test (Bernhardt & Anderson, 2005); successive vertical jumps (Kraemer et al., 1996); or isokinetic knee extensions and flexions (Joyce, Bernier, & Perrin, 1994). Results suggested that no significant differences occurred with maximum vertical jump, one repetition maximum, and total work capacity (Joyce, Bernier, and Perrin, 1994; Kraemer et al., 1996; Kraemer et al., 2000; Doan et al., 2003; Bernhardt & Anderson, 2005). No significant differences were seen with average power output with the use of limb compression (30mmHg) (Joyce, Bernier, & Perrin; 1994).

Discrepancies exist within the research when investigating the influence of limb compression on physiological mechanisms. No set standards have been set for limb compression, such as compression levels, materials, and protocols. These discrepancies, including the use of animal versus human models, which make it difficult to make direct comparisons across research studies. Contradictory research adds to the inconsistencies with limb compression research. Exercise protocols can vary depending on the interests of the investigators. It is possible, however, to discover common traits in the limb compression and exercise protocols to allow for general statements regarding its use. The previously mentioned research suggests that there are changes in physiological mechanisms similar to what is seen in medical research. It is suggested that limb compression provides no performance gains within a variety of measures. Table 2 presents a summary of these changes in measures and mechanisms with compression and exercise.

Table 2. Compression, Exercise and Performance Mechanisms

Mechanism/Performance	**Effect**	**Compression Level**	**References**
Blood Vessel Size	↓	N/A	19
Skin Temperature	↑	N/A	11,12
Blood Pressure	↑	N/A	4
Heart Rate	=	N/A	2,4,12
Creatine Kinase	↓	N/A	12
Blood Lactate	↓*	N/A	6,7,12
VO_2 Max	=	N/A	6
Fatigue (time to fail)	=	N/A	5,6
Balance	=	N/A	5
Max Vertical Jump	=	N/A	5,11,18
Agility	=	N/A	5
Speed	=	N/A	2,11,5
One Repetition Maximum	=	N/A	19
Average Power Output	↑	N/A	18
Total Work Capacity	=	30 mmHg	17,19
Range of Motion	↓	N/A	5,11

* Questionable during exercise (Berry & McMurrey, 1987; Berry et al., 1990)

= no significant difference

Summary

Everyday there are advancements in sports technology. It is the goal of most recreational and professional athletes to perform at their top level. Claims from manufacturers that promise to provide performance gains while wearing compression garments are very attractive to athletes. During this evolution in sport, it is necessary for athletes, coaches, and recreational enthusiasts to be able to distinguish truth from fact. It is necessary to understand the physiological mechanisms associated with a response, and what implications that response has. It seems that the current literature is somewhat inconclusive as to limb compression and performance improvements. These inconsistencies are caused by the lack of standards set for limb compression and different methodological techniques. Until the scientific community determines standards for compression research, it will remain difficult to compare research directly. Additionally, it is necessary to continue to look at the mechanisms associated with limb compression to validate performance gains. Little evidence exists that supports the use of limb compression for performance gains. Until standardization in limb compression research is accomplished, the potential for performance gains will remain elusive. This study tested the null hypothesizes that there would be no significant differences in the forces generated during a vertical jump and electromyography between the control, of no compression, and experimental conditions (different levels of compression). This study addressed variables that suggest potential mechanisms for improvement in performance, such as velocity at takeoff, fatigability, and surface electromyography, with limb compression. The methods used to test these hypothesizes are discussed, in detail, in the next chapter.

Chapter Three

Methods

Subjects

Twenty-five male subjects aged 18-30 volunteered to participate in the study. The study was designed to observe the influence of limb compression on the forces generated during a vertical jump. Each subject had to be able to fit into medium- sized compression shorts (based on manufacturer sizing). All subjects were male to minimize any confounding variables, such as anatomical differences. The study was unable to be double blind due to the subject's knowledge of the type of compression garment. It is unknown if the subjects had preconceived notions as to the benefit or disadvantage of the use of compression garments on performance enhancement. All subjects' thighs were measured and the circumferences fell within physiological ranges (Dempster, 1967; Clauser, McConville, & Young; 1984)(Appendix 17). All subjects completed all conditions and all trials.

Suit Measurement

All suits were measured to ensure conformity. Using a tape measure, the circumferences in waistband, mid-thigh, and bottom leg cuff were recorded (Appendix 16). The distance between each panel on the right leg was measured to determine if panel placement was the same for each suit. Differences noted in the suits were recorded and suggested to have an impact on the results.

Experimental Procedure

The experimental protocol was approved by Indiana University-Bloomington Human Subjects Internal Review Board (Study #08-13371) (Appendix 18). Each subject was given a verbal explanation of the informed consent, and then asked to sign it. Each subject was asked to participate in the study that consisted of the following: familiarization, four maximal voluntary contractions (MVCs), and three conditions of ten vertical jumps on a platform. Based on Kraemer et al. (1996), each condition consisted of ten jumps. Before any testing began, the subject was taken to warm-up, which consisted of cycling on a monarch cycle ergometer with a 1-kg resistance for five minutes, after which, familiarization occurred. This lasted as long as needed for each subject to feel comfortable with all the equipment and protocol being used. The familiarization took place in the laboratory, and allowed the subjects to practice the experimental protocol on the equipment (Linthorne et al., 2001) until they felt comfortable with the testing procedures. All testing took place on the same day and took approximately an hour and a half to complete.

After warm-up and familiarization, subjects were taken and measured for the placement of non-invasive surface electromyography (EMG) electrodes. Surface electromyography allowed for potential differences in muscle activity to be recorded during the vertical jump. The EMG electrodes were placed on the rectus femoris and bicep femoris of the dominant leg (Thorlund et al., 2008). The dominant leg was determined by asking the subject which leg they considered their dominant one. The electrode on the rectus femoris was placed on the anterior midline of the thigh, midway between the proximal border of the patella and the inguinal crease of the hip. The electrode on the bicep femoris was placed on the posterior midline of the thigh, midway between the hamstring insertion into the gluteus maximus and the posterior proximal border of the knee. This spot was ensured by a mark made at the initial measurement. As each electrode was placed, non-compressive shorts (control garment) were put over it. The control garment provided protection and secured each electrode. If one happened to fall off during changing, a different electrode was placed in the same spot. The EMG electrodes recorded the muscle activity and MVCs in the dominant leg during each condition. The EMG recording uncovered any potential differences in muscle activity with the use of limb compression. All EMG information was recorded using the Acknowledge (Biodex Corporation Version 2.0) program on the laboratory computer.

After warm-up and familiarization, each subject conducted MVCs with the rectus femoris and bicep femoris. Four MVCs were performed with both the rectus femoris, via knee extension, and the biceps femoris, via knee flexion. Each subject was given four attempts at the MVC and encouraged to give a maximal effort. Out of the four attempts, the one with the highest EMG amplitude was used to represent the MVC (Yasuda et al., 2008). The EMG amplitude from that MVC was compared with the vertical jump EMG amplitude. The MVCs were reported in maximum volts achieved and conducted on a Biodex Machine using Biodex Advantage Software Version 2.0. All data was recorded using Acknowledge on the laboratory computer.

The experiment consisted of three randomized conditions: regular fitting compression (proper manufacturer-sized shorts), undersized compression (one size smaller than manufacturer-sized shorts), and oversized compression (one size larger than manufacturer-sized shorts). All compression garments were commercially available to the public. The compression garment chosen for this study was the LZR Jammer by Speedo. The length of the Jammer was chosen to control the amount of suit covering any joint (Harman & Frykman, 1990). By not covering multiple joints, the LZR Jammer allowed the experiment to eliminate the potential for "torque generation." Ten minutes was allowed between each condition allowed for recovery (Kraemer et al., 1996), as well as changing time.

The different sized shorts were randomly placed in front of each subject. The subjects did not know the sizes of any short. They then randomly chose a short to wear. After the short was put on, the thigh circumference was measured. Each subject was required to do three different conditions of vertical jump, and each consisted of ten jumps under one of the three randomized conditions (Kraemer et al., 1996). Each subject was placed on a Kessler force plate and told to squat down until their knee reached ninety degrees. The subjects had their hands on their hips at all times to eliminate the aid of an arm swing (Linthorne, 2001). Ten minutes were given for recovery and changing time between each randomized condition. The testing ended once all conditions were completed. All data was recording using Acknowledge on the laboratory computer.

After initial analysis, eleven subjects were chosen randomly to come back into the laboratory for further testing. The second data set was used to directly compare the control of no compression with the experimental condition of undersized compression. Eleven subjects were used to determine if the potential for any significant differences would occur between the control and undersized compression conditions. Each of the eleven subjects completed a trial of control jumps and undersized compression jumps. The control jumps allowed for direct comparison of the control versus the undersized compression condition. Electrodes were placed in the same positions as previously described. Each subject provided ten jumps in each of the two conditions. All data for the vertical jump and EMG were recorded on the computer using the Acknowledge program.

Compression Quantification

To estimate the amount of compression elicited on each subject, measurements were taken on each suit. Two dots were placed on each size of the compression and control garments. The dots were placed on the midpoint of the right thigh pant length. The initial distance of the dots, with no stretch, was measured with a cloth tape measure. The recorded distance was considered the resting measurement. The subject would put on the compression garment, and the distance between the dots was measured again with the cloth tap measure. This distance was considered the stretched distance. Using a custom-made device described in the following section, the compression garments were taken and stretched. The following were measured using the stretching device: dot stretch, circumference, and pressure elicited on the device. The data was used to construct regression lines that defined the pressure-circumference relationship associated with each compression and control garment.

Stretching Device

This study reported direct pressures (in mmHg) exuded by the short on each subject. The investigator developed an apparatus that allowed for a direct pressure reading. The device was advantageous in that it incorporated direct pressure readings at different circumferences. This posed a difficult task, as it required an expandable device that can read direct pressures and maintain certain properties. To obtain direct pressure measurements, it is necessary to use a cylinder model as opposed to a spherical model (Mirsky, 1969). Due to Laplace's Law, a spherical model will have decreases in pressure past a certain stretch, (Mirsky, 1969). A decrease in pressure would lead to false results. The current study employed a cylinder bladder that could be inserted into the leg of each compression garment. The bladder could be inflated to a certain circumference and the pressure reading from a mercury column recorded. The system was designed to be a closed system to allow the addition or subtraction of volume in the bladder. The volume affected every other property of the system. The custom-made stretching device comprised of a one-way valve connected to an inflatable rubber bladder attached to a mercury pressure column. The device allowed air to be passed into the bladder while giving an internal, instantaneous pressure reading in mmHg. The device was passed through the leg of the compression short. The pressure, circumference, and dot stretch were recorded for every 2-mmHg increase. The recorded data coincided with the physiological ranges for thigh circumferences seen in research (Dempster et al., 1967; Clauser et al., 1984).

Data Analysis

Two data sets were analyzed. The initial data setup was constructed by using a randomized block design. The dependent measures consisted of the surface EMG, fatigability, and velocity at takeoff (Vto) in all conditions. The independent variables consisted of the oversized, regular, and undersized compression garments (Kraemer et al., 1996; Linthorne, 2001). The randomized block design tested both hypothesizes that stated there is no significant difference in surface EMG and the forces generated during a vertical jump, when using limb compression. The second data set was analyzed with T-tests for the control and undersized compression garment. The independent variable was the two different garments. The dependent variables were the surface EMG, fatigability, and Vto (Kraemer et al., 1996; Linthorne, 2001). The first data set was analyzed using repeated measures ANOVA using a significance P>.05 while a T-test was performed for the second data set. The results of the experiment are summarized in the following chapter.

Chapter Four

Results

Introduction

This study was designed to test the null hypothesizes that limb compression would produce no significant differences in the forces generated or electromyography in the thighs. These results were determined as comparing the control of no compression versus the experimental condition of different levels of compression. The results of the experiment are summarized in the following chapter.

First Data Subset

Table 3 shows the descriptive statistics for all the male participants in the study.

Table 3. Subject descriptives for the male participants.

N=25	Mean ± SD
Age	22.8±3.3
Weight (kg)	75.1±6.7
Height (cm)	176.6±5.8
Thigh Circumference (cm)	54.3±1.6
Maximal Voluntary Contraction Ham (volts)	1.02±0.5
Maximal Voluntary Contraction Quad (volts)	0.97±0.5

It was necessary to measure the shorts used in the experiment to ensure conformity. Each short was measured, with a tape measure, at the waistband, mid-thigh, and lower leg band. When investigating the LZR jammer it was discovered, through measurement, that the differences occurred, across short sizes, in the waistband only.

Table 4. LZR jammer descriptives.

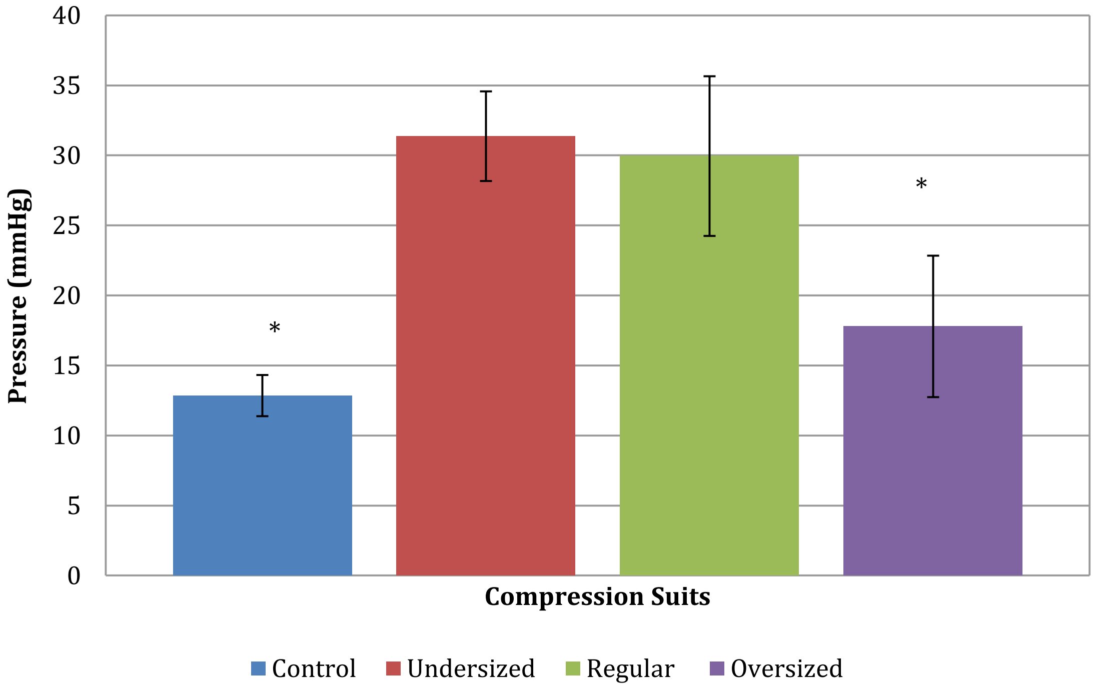
Measurement site	Undersized	Regular Fitting	Oversized
Waist Band (cm)	50.0±0.2	57.6±0.1	61.2±0.1
Mid Thigh (cm)	45.4±0.1	45.6±0.1	46.4±0.1
Lower Leg Band (cm)	34.3±0.1	34.5±0.1	35.7±0.2

Table 4 shows that the differences in short manufacturing occur at the level of the waistband only, with all sizes. This difference suggests that the manufacturers may use a "base" short made of elastic material. To make a different size short the manufacturer then adds a particular size waistband. This process negates the idea of individualized sizing.

Compression Quantification

To estimate the compression levels on each subject, a custom apparatus was developed by the investigator. Figure 1 summarizes the differences in compression levels of each short compared to the other shorts. Repeated measures ANOVA ($P<0.05$) resulted in significant differences in the compression levels elicited on each subject.

Figure 1. Average compression levels of four different conditions.



* Denotes significant difference

Figure 1 show that significant differences occur, in the levels of compression, for each size short. The results suggest that the different size compression short did produce significantly different compression levels when compared to each other. Figure 1 shows that the undersized compression produced the most compression, which was expected. The significant difference in compression levels mean that a treatment existed when compared to the control.

It was advantageous to develop the ability to inform athletes of how much compression they would experience when wearing the LZR jammer. This would allow athletes to decide on which short they would prefer according to thigh size and pressures elicited by the short. The regression lines are summarized in Table 6.

Table 5. Regression equations for each condition

Condition	Pressure vs. Circumference Regression Line
Control	Y=1.68990x-75.786
Undersized	Y=3.4744x-152.060
Regular fitting	Y=3.6446x-167.980
Oversized	Y=4.8685x-235.050

Figure 2. Pressure versus circumference for each condition as compared to the bladder apparatus.

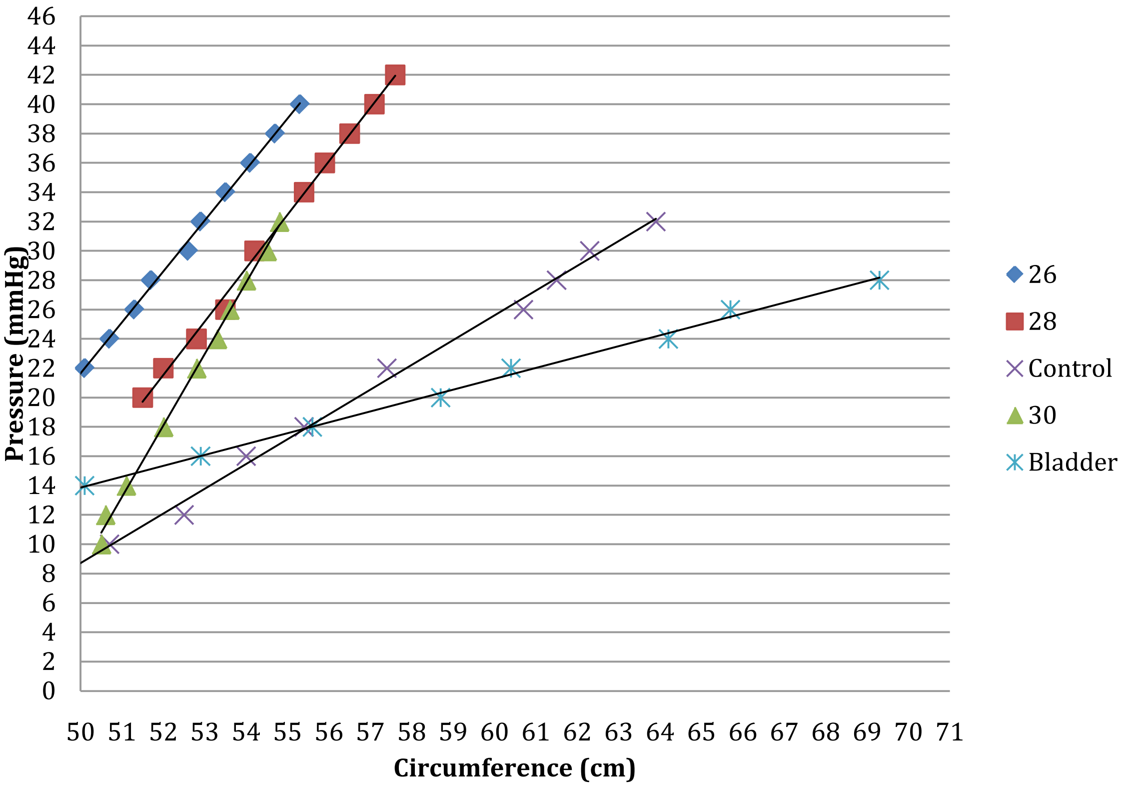


Table 5 shows the regression lines that developed from plotting the lines shown in Figure 2. The sizing of the suit is as follows: 26 represents Undersized, 28 represents Regular fitting, 30 represents Oversized. The bladder condition represents the pressures elicited by the stretching device itself. The regression equations make it possible for one to estimate a pressure elicited by the LZR jammer by simply knowing the circumference of the wearer's thigh. It is of interest to note that Figure 2 suggests that, during the experiment, the short sizes 30 and 28 reacted similarly. This is enforced by the fact that the short size 26 was found to have more elastic material than sizes 30 or 28.

MVC EMG analysis

Pre-trial values were analyzed to determine if the hamstrings were able to produced significantly more force that the quadriceps and vice versa. A T-test resulted in no significant differences in the pre-trial maximal voluntary contraction EMG for both the hamstring and quadricep (See Fig 3, and Appendices 1 and 2).

Figure 3. Average maximal voluntary contraction – EMG.

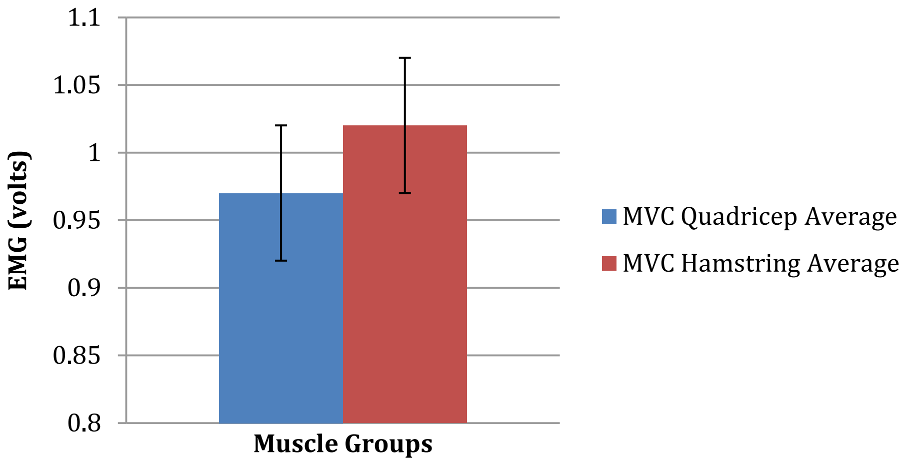


Figure 3 shows that no significant difference occurred during the pre-trial MVCs. The result suggests that each subject's muscle activity in the quadricep and hamstring, of the dominant leg, were not statistically different. This suggests that an imbalance would not occur in force production during the vertical jump.

Conditions EMG analysis

To determine no neural differences existed with the use of limb compression, surface Electromyography (EMG) was collected. Repeated measures ANOVA resulted in no significant differences in the EMG activity for each condition for the average amplitudes of both the hamstring and quadricep (See Figure 4, and Appendices 3 and 4).

Figure 4. EMG of compressed musculature during vertical jump

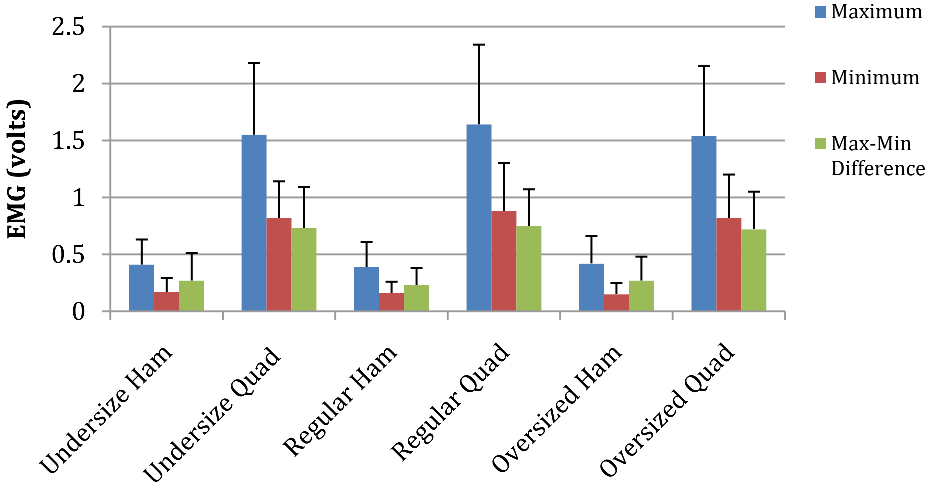


Figure 4 shows that no significant differences occurred in surface EMG during the vertical jump test when comparing hamstring data for each short and quadriceps data for each short.

Conditions analysis

Velocity at takeoff was recorded in order to determine if significant differences existed between the control, no compression, and the experimental conditions, compression. Repeated measures ANOVA resulted in no significant changes in Vto with any condition for compression, trial (each jump), or compression and trial (Appendix 5). Repeated measures ANOVA also showed no significant differences in Vto between conditions for the maximum, minimum, and difference between maximum and minimum for the vertical jumps (See Figures 5, 6, 7 and 8, and Appendices 5 and 6 for the summarized data).

Figure 5. Average Vto for the vertical jump for the participants.

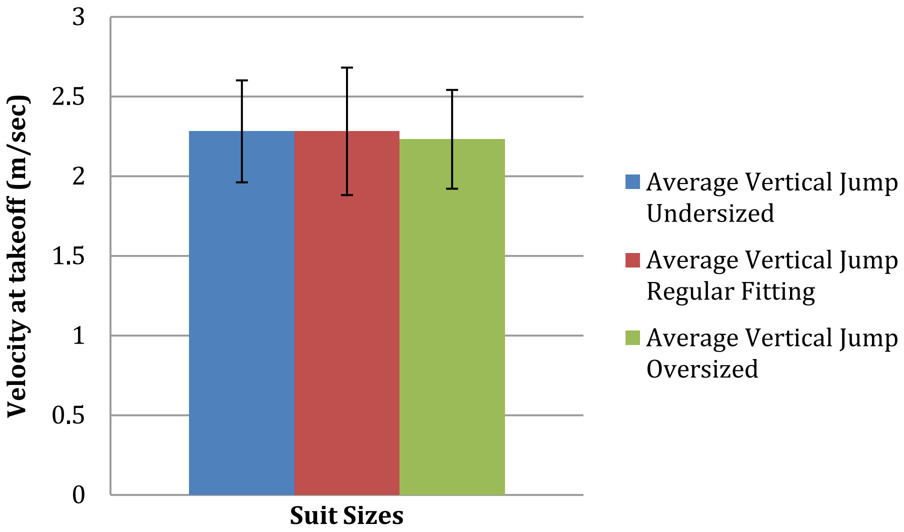


Figure 5 shows that no significant differences occur with the use of different levels of compression.

Figure 6. Maximum Vto for vertical jump for all subjects.

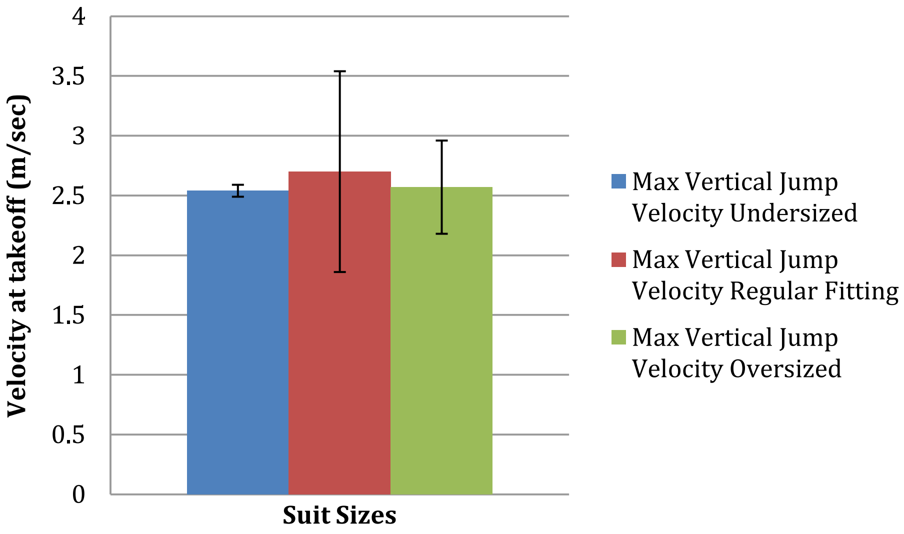


Figure 7. Minimum Vto for the vertical jump for all subjects.

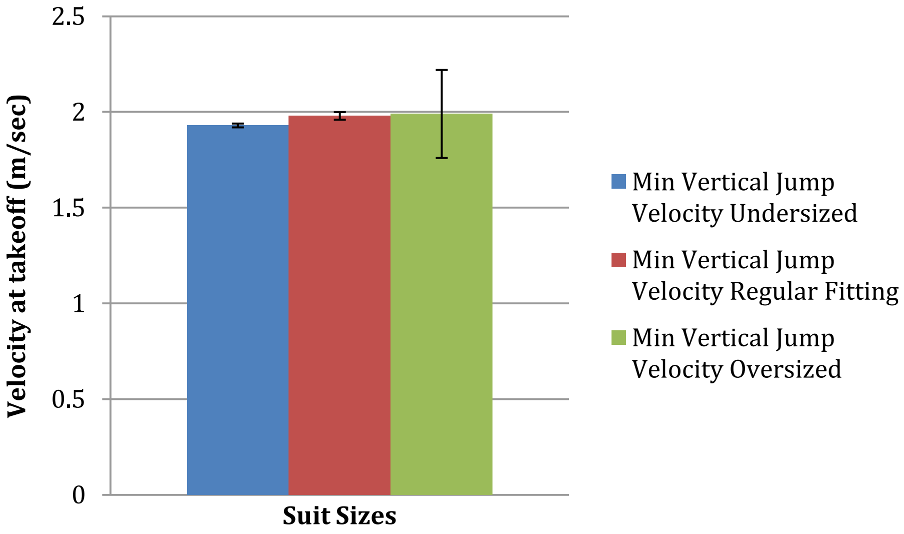


Figure 8. Maximum-minimum difference in the Vto for the vertical jump

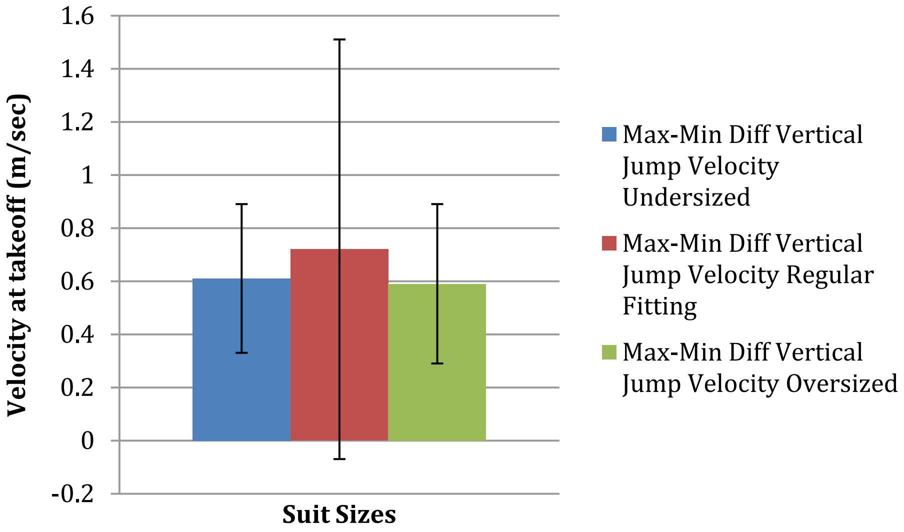


Figure 5,6,7 and 8 show that no significant differences occur with the use of different levels of compression.

Fatigability

Kraemer (1996) suggested that limb compression resulted in higher average power output (Kraemer et al., 1996). To either confirm or reject this claim, the average Vto for the first three and last three jumps were analyzed. The average Vto for trials 1, 2, and 3 were plotted with the average Vto for trials 8, 9, and 10. The averages were analyzed using a Repeated Measures ANOVA which resulted in no significant differences for any of the conditions (See Figures 9, 10, 11 and Appendix 7).

Figure 9. Fatigability via Vto of vertical jump for oversized suit.

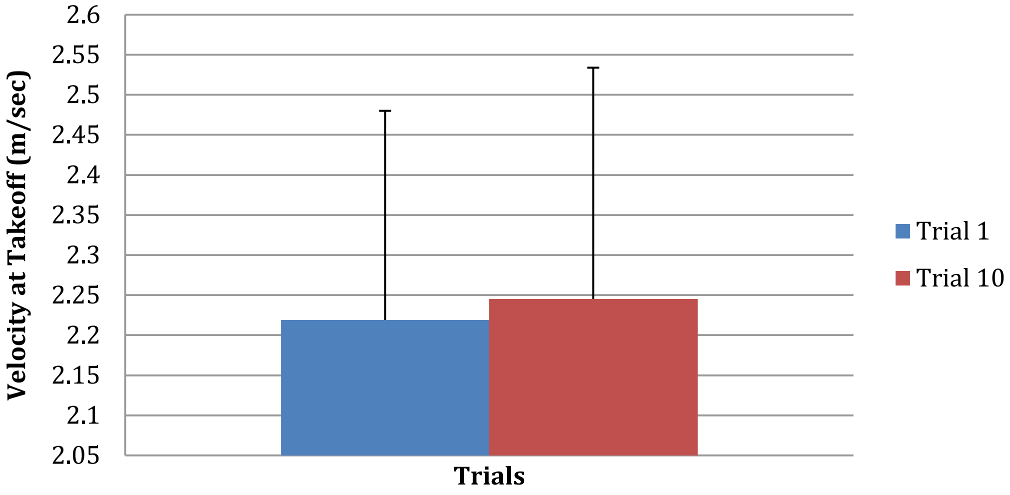


Figure 10. Fatigability via Vto of the vertical jump for the regular sized suit.

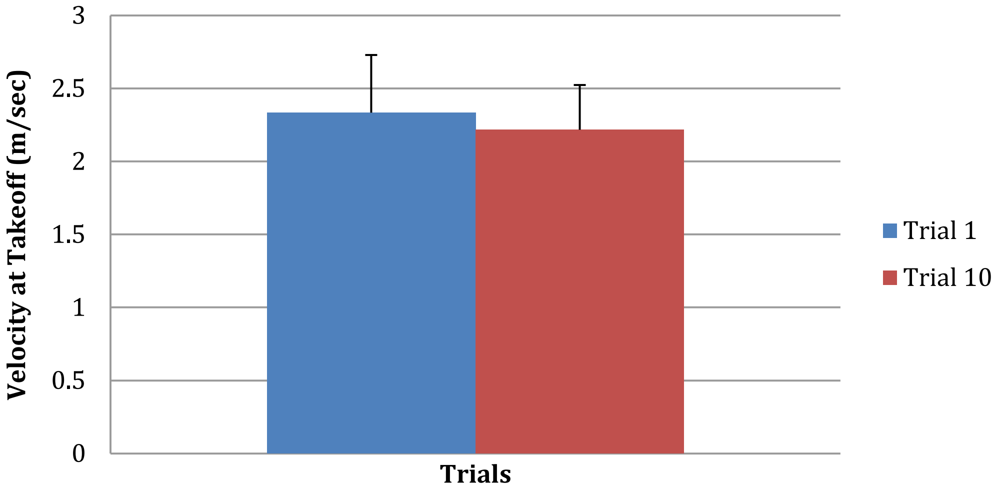
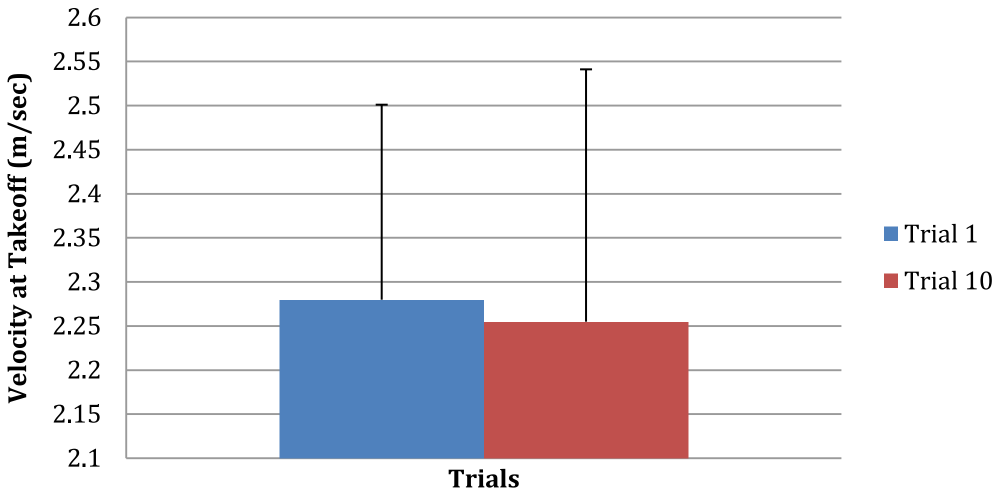


Figure 11. Fatigability via Vto of the vertical jump for the undersized suit.



Figures 9, 10, and 11 show that no significant differences occurred in the averages in the Vto across the first three and last three jumps.

Eleven subjects were randomly chosen to in a second study in order to provide a direct comparison between the undersized compression short with the control condition of no compression. The following results are supportive of the null hypothesis that no significant difference would occur with the use of limb compression when compared to the control of no compression.

Second Data Subset

Table 6. Subject descriptives for the second data subset.

N=11	Values±SD
Age	24.3±3.4
Weight (kg)	74.5±7
Height (cm)	175.4±5.5
Thigh Circumference (cm)	53.9±1.6
Maximal Voluntary	1.12±0.4

Contraction Ham (volts)	
Maximal Voluntary Contraction Quad (volts)	1.25±0.6

Table 6 shows the descriptive statistics for the second data subset of eleven subjects. These eleven subjects were chosen randomly out of the original group of twenty-five subjects.

MVC EMG analysis

It is theorized that the use of limb compression would not affect the neuromuscular activity, measured by electromyography in the thigh of each subject when compared to the control of no compression. In order to determine if any significant differences already existed in the subject's thighs, MVC's were conducted on both the quadricep and hamstring of each subject. This allowed the study to suggest any potential imbalances and the electromyography associated with maximal effort. Repeated measures ANOVA resulted in no significant differences in the maximum voluntary contraction EMG for both hamstring and quadriceps (See Figure 12, and Appendices 8 and 9).

Figure 12. Average maximum voluntary contraction as measured by the EMG.

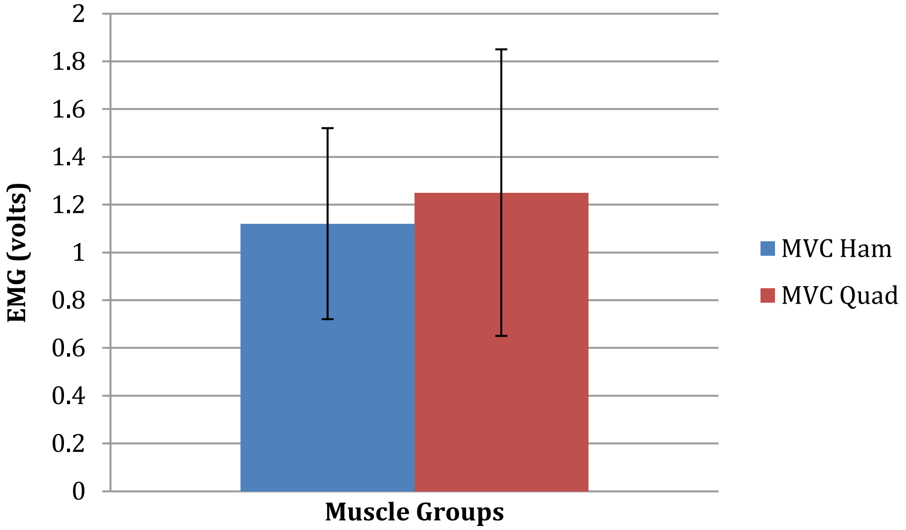


Figure 12 show that no significant differences existed, for the average force, represented by volts, of each subject, in the MVC's for both the quadriceps and hamstrings.

Control vs. Undersized Compression EMG analysis

Surface electromyography was recorded during this study in order to determine if significant differences would result, during a vertical jump, from the use of limb compression. Repeated measures ANOVA resulted in no significant differences in the average EMG activity for both the control and the compression of the undersized garment for the both the hamstring and quadricep (See Figure 13, and Appendix 10 and 11).

Figure 13. Average EMG readings, for the quadricep and hamstring, for limb compression and control.

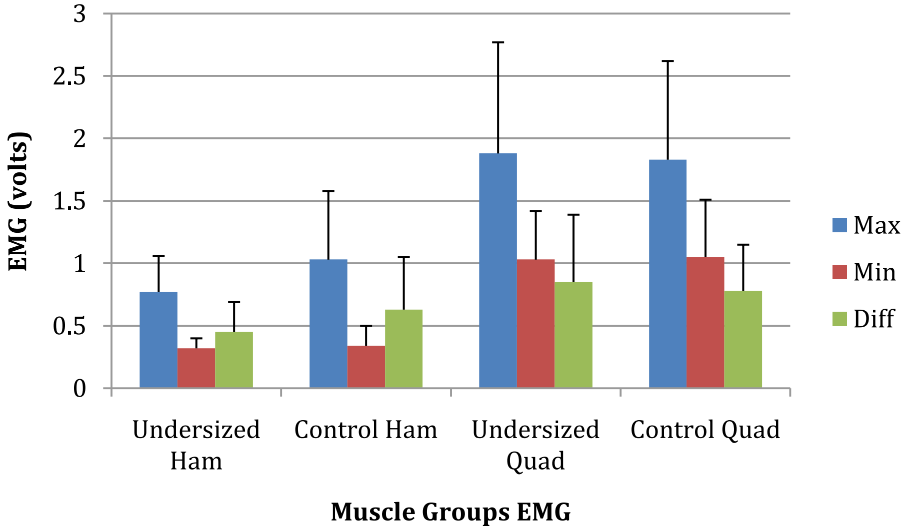


Figure 13 show that the use of limb compression provided no significant influence on the surface electromyography as compared to the control for both the hamstring and quadricep.

Conditions analysis

Figure 14 shows the results from the T-test showed no significant differences in Vto within the control and compression trial, or compression and trial (See Appendix 12). The T-Test also resulted in no significant changes in Vto with any condition for the maximum, minimum, and difference in vertical jumps (See Fig 14, 15, 16, 17, and Appendix 8).

Figure 14. Average Vto during the vertical jump for both undersized and control conditions.

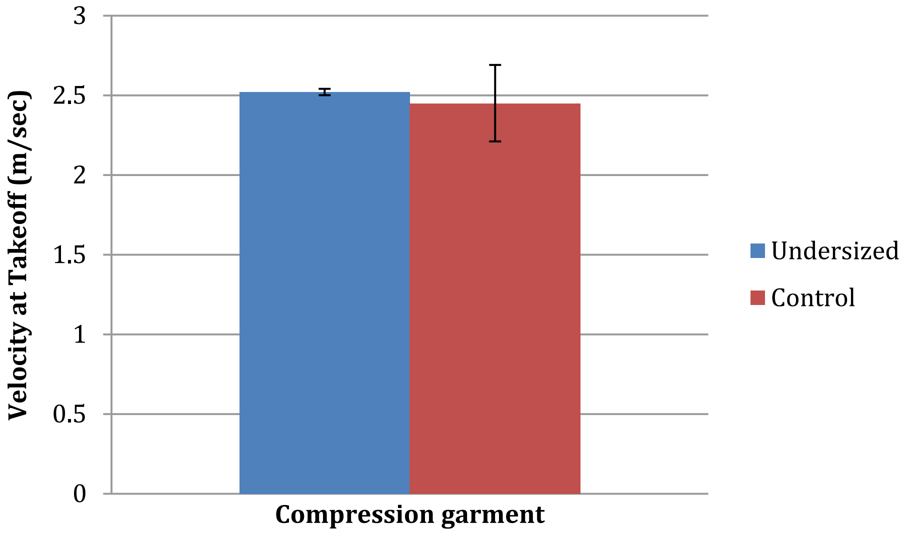


Figure 15. Maximum Vto in the vertical jump for both undersized and control

conditions.

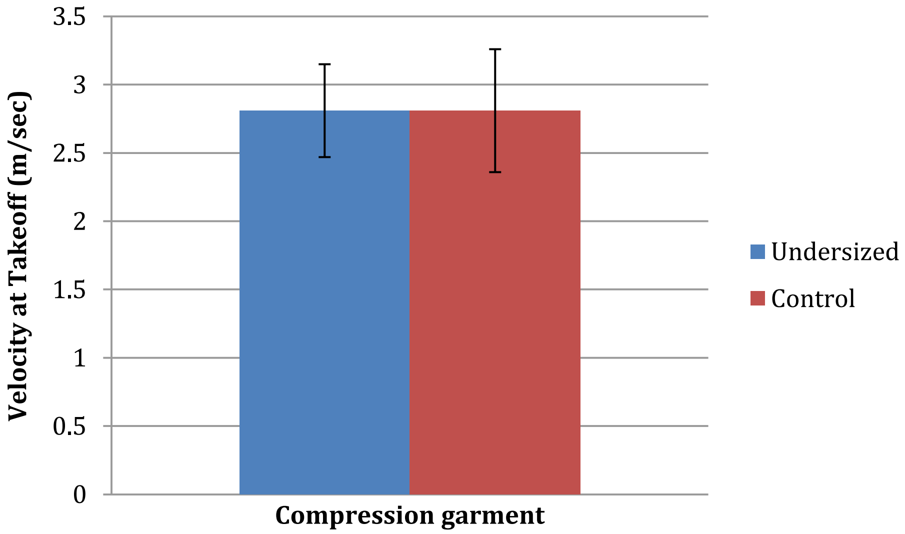


Figure 16. Minimum Vto in the vertical jump for both the undersized and control conditions.

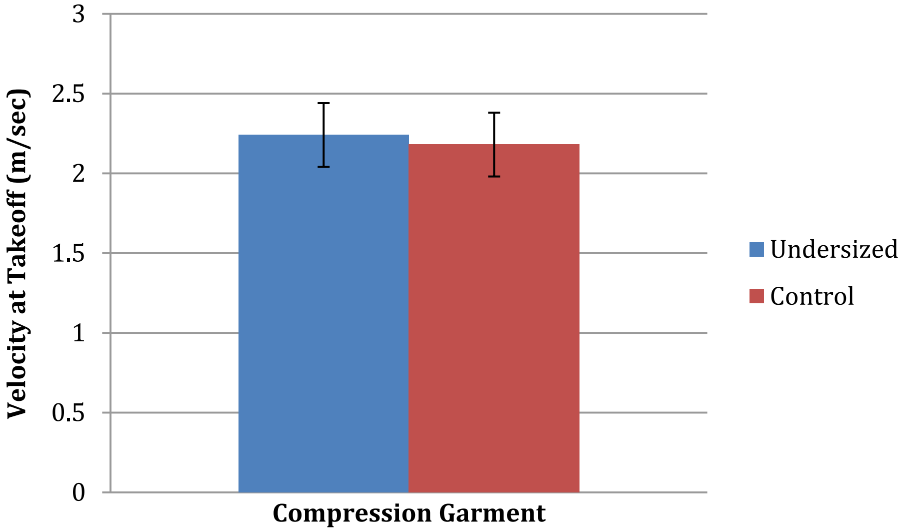
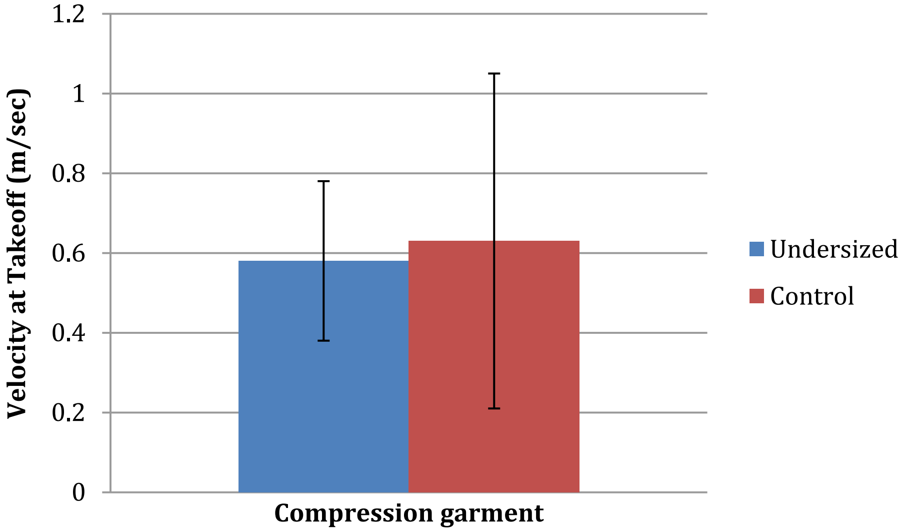


Figure 17. Maximum-minimum difference in Vto during the vertical jump for both the undersized and control conditions.



Figures 14 through 17 show that the use of limb compression provided no significant performance gains in any of the variables measured in the vertical jump.

Fatigability

To determine if the average impulse produced was influenced with the use of limb compression; the average Vto for trials 1, 2, and 3 were plotted with the average Vto for trials 8, 9, and 10.

Figure 18. Fatigability via Vto for the vertical jump for the control test.

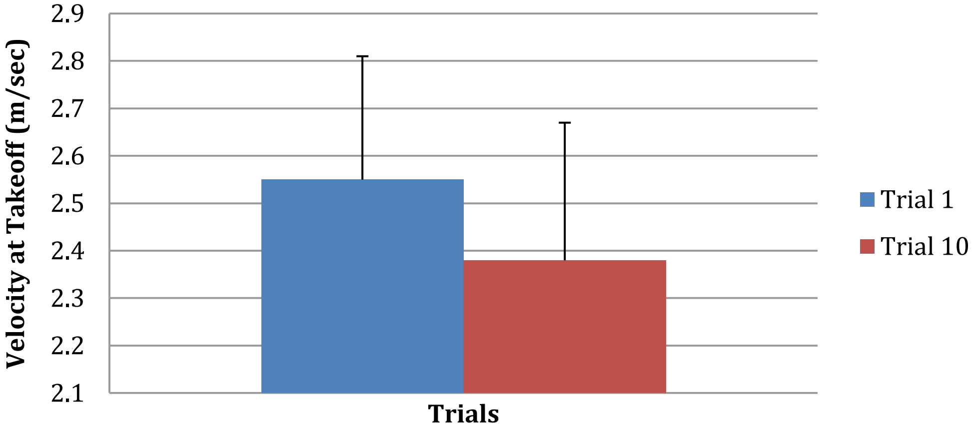
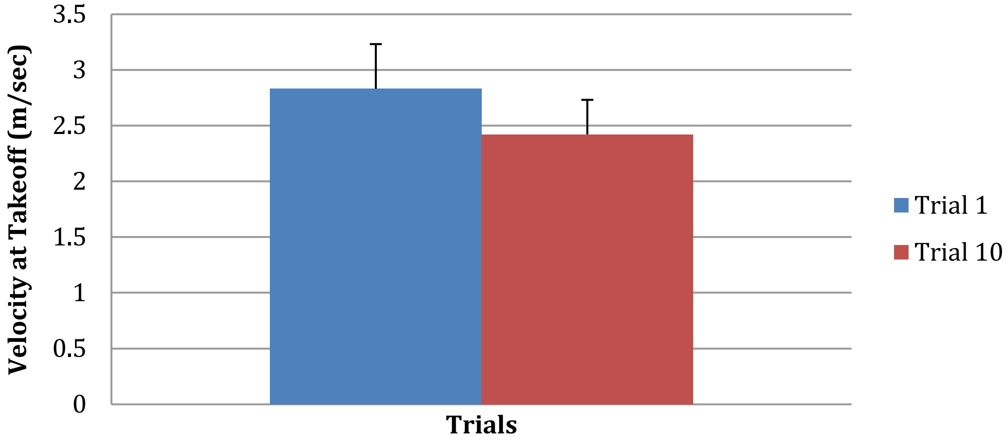


Figure 19. Fatigability via Vto of the vertical jump for the undersized suit.



Figures 18 and 19 show that no significant differences occurred, with fatigability, with the use of limb compression as compared to the control.

Chapter Five

Discussion

This study has demonstrated that the use of limb compression shorts would provide no performance benefit during the vertical jump test. For any conditions the average, maximum, minimum, and difference of the maximum and mimimum velocity at takeoff was not significantly different. Further, the electromyography results suggest that the use of limb compression shorts did not have a significant effect on neuromuscular activity.

Compression Garments

The compression garment chosen for this study was the LZR jammer by Speedo. The implications of this study apply to any sport utilizing limb compression for the purposes of improving performance. The length of the jammer was chosen to control the amount of suit covering any joint (Harman & Frykman, 1990). By not covering multiple joints, the LZR jammer allowed the study to eliminate the potential for "torque generation." Torque generation is suggested to occur when wearing suits that cover multiple joints and affect the forces that can be generated during force production (Harman & Frykman; 1990; Doan et al., 2003). The compressive qualities of the LZR are advertised to promote increases in performance. One strategy used by the manufacturer employed non-compliant panels placed on the short over an elastic base material.

It is important to note that this study intended to study potential mechanisms of improvements in performance. Multiple studies have investigated performance changes, with the use of compression garments, but have proven inconsistent (Berry et al., 1990; Kraemer et al., 1996; Kraemer et al., 1998; Kraemer et al., 2000; Doan et al., 2003; Bernhardt et al., 2005). Three different sizes of the LZR, allowed for different levels of compression to be investigated.

Compression Quantification

This study sought to determine if the different sized shorts provided different levels of compression. This study also evaluated if a possibility of greater improvement in performance existed with different levels of compression. In previous studies, force transducers sewn into the leg of the shorts evaluated compression values (Kraemer et al., 1996). This study utilized a different approach for compression evaluation. Kraemer (1996) measured the compression with force transducers but failed to report actual compressive forces of the suit. Kraemer (1996) only reported that the undersized compression suit elicited higher compressive forces than the regular fitting, and the control was said to have a compressive force of 0 (Kraemer et al., 1996). This study reported direct pressures (in mmHg) exuded by the short on each subject. An apparatus that allowed for a direct pressure reading was developed. The device was advantageous in that it incorporated direct pressure readings at different circumferences. This posed a difficult task, as it required an expandable device that can read direct pressures and maintain certain properties. To obtain direct pressure measurements, it is necessary to use a cylinder model as opposed to a spherical model (Mirsky, 1969). Due to

Laplace's Law, a spherical model will have decreases in pressure past a certain stretch, (Mirsky, 1969). A decrease in pressure would lead to false results. The current study employed a cylinder bladder that could be inserted into the leg of each compression garment. The bladder could be inflated to a certain circumference and the pressure reading from a mercury column recorded. The system was designed to be a closed to allow more volume in the bladder. More volume affected every other property of the system. Other measurement systems, such as the kikumhime pressure monitoring system (Trenell et al., 2006) were designed to give direct pressure readings with a pressure sensor. The kikumhime system lacks the ability to increase or decrease the circumference of the material under stretch at will.

The data recorded during the study made it possible to create a regression line for each suit. The regression line allowed the investigator to know exactly what pressure was being applied for any given amount of stretch in the suit. With the data plotted, the slopes of pressure versus circumference, stretch versus circumference, and pressure versus stretch for each suit are different (for these results see Appendices 13, 14, and 15). The slopes were of interest, as the LZR jammers are all purported to be made the "same way" with the same material. In an attempt to understand why the slopes were different, through measurement, it was discovered that the amount of elastic material varies between shorts. The undersized short had more elastic material than the regular fitting short. The regular fitting short and the oversized short had very closely related elastic material as explained by the closeness of pressures elicited by each suit (for these results see Appendix 15). Upon further investigation, it was shown that the circumferences of the suits at different points proved to be similar, with the exception of the waistband (for these results see Appendix 16). The shorts provided different levels of compression, but reacted differently for any given stretch.

Vertical Velocity at takeoff and EMG

There were no significant differences in vertical Vto for any condition. The results suggest that limb compression has no effect on the jumping ability of the subjects. The data from the present study confirm previous findings in which no significant difference was found with the vertical jump with the use of limb compression (Kraemer et al., 2000; Bernhardt & Anderson, 2005). To investigate if there were any neural changes in response to limb compression, surface electromyography (EMG) was recorded. No significant difference in surface EMG was reported. The results suggest that limb compression has no neural effect on the vertical jumping ability of the subjects. The EMG results disagree with previous findings where limb compression elicited changes in EMG. (Yasuada et al., 2008). Due to differences in the present study and previous studies it is difficult to distinguish if the differences seen in electromyography are due to the different pressure elicited on the muscle during each study. No significant differences were reported with both vertical Vto and surface EMG.

Fatigability

Fatigability was assessed from the vertical Vto across trials. No fatiguing affect was seen. The results may be due, in part, to each subject having more time between jumps than in other studies (Kraemer et al., 1996). The increase in recovery time may manifest itself in the form of a non-existence fatigability curve.

The results may also be due to the subjects not giving maximal efforts for each jump, despite encouragement given by the investigator. The fatigability results were not consistent with previous findings where average force during the vertical jump was shown to be higher (Kraemer et al., 1996). Kraemer (1996) enlisted the help of trained NCAA Division I volleyball players that were shown to elicit a fatigue curve (Kraemer et al., 1996). Any subject that was unable to produce this fatigue curve was not asked to participate in the study (Kraemer et al., 1996).

Conclusions

The use of compression garments is widespread in athletics. This study suggests that limb compression shorts provide no improvements in performance during a vertical jump test. This study was designed to discover the potential mechanisms for improved performance with the use of limb compression. Specifically, improvements and neural changes associated with the vertical jump. The methods used in the current study were different from other methods, specifically in compression quantification and recovery procedures (Kraemer et al., 1996). The use of trained jumpers could have an impact on the results, as this study did not employ trained jumpers. Trained jumps have the experience to produce maximal jumps during short periods of time repeatedly. It is of interest to note that the subjects in Kraemer's (1996) study could have a bias to form fitting shorts as volleyball players normally wear form fitting shorts and potentially have a biased toward compression clothing (Kraemer et al., 1996). Differences in compression quantification and rest procedures may provide insight as to why the results are contradictory. Measurements that are more sensitive would also provide better insight into the potential mechanisms of limb compression. Future researchers need to develop the proposed testing method using equipment that is more sensitive, and need to note the limitations of force plate and surface EMG data. Limitations include crystal drift in the force plate and smoothing surface EMG data. More in-depth neural changes with limb compression would also be necessary. In-depth analysis may be accomplished by testing variables, such as H-reflex and Renshaw cell activity to determine inhibition activity. To determine the possibility for potential "torque generation," studies should be conducted utilizing suits that cover multiple joints. Further investigation is warranted for the use of different compression garments such as compression socks to determine any performance benefits to the wearer and determine the mechanisms behind such possible increases in performance. Although compression short garments are widespread in athletics, it seems that they provide no performance enhancement during a vertical jump test for the wearer.

Appendices

Appendix 1. Maximal Voluntary Contraction EMG for Hamstring

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
trials	Sphericity Assumed	.072	3	.024	.638	.593	.026	1.914	.177
	Greenhouse-Geisser	.072	2.546	.028	.638	.568	.026	1.625	.166
	Huynh-Feldt	.072	2.874	.025	.638	.586	.026	1.834	.174
	Lower-bound	.072	1.000	.072	.638	.432	.026	.638	.120
Error(trials)	Sphericity Assumed	2.705	72	.038					
	Greenhouse-Geisser	2.705	61.109	.044					
	Huynh-Feldt	2.705	68.972	.039					
	Lower-bound	2.705	24.000	.113					

a. Computed using alpha = .05

Appendix 2. Maximal Voluntary Contraction EMG for the Quadricep

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
trials	Sphericity Assumed	.445	3	.148	1.109	.351	.044	3.327	.287
	Greenhouse-Geisser	.445	2.604	.171	1.109	.347	.044	2.887	.267
	Huynh-Feldt	.445	2.949	.151	1.109	.351	.044	3.270	.285
	Lower-bound	.445	1.000	.445	1.109	.303	.044	1.109	.173
Error(trials)	Sphericity Assumed	9.631	72	.134					
	Greenhouse-Geisser	9.631	62.493	.154					
	Huynh-Feldt	9.631	70.775	.136					
	Lower-bound	9.631	24.000	.401					

a. Computed using alpha = .05

Appendix 3. EMG Averages for the Hamstring

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^{a}
emg	Sphericity Assumed	.065	2	.033	1.170	.319	.046	2.341	.245
	Greenhouse-Geisser	.065	1.870	.035	1.170	.317	.046	2.188	.237
	Huynh-Feldt	.065	2.000	.033	1.170	.319	.046	2.341	.245
	Lower-bound	.065	1.000	.065	1.170	.290	.046	1.170	.180
Error(emg)	Sphericity Assumed	1.342	48	.028					
	Greenhouse-Geisser	1.342	44.881	.030					
	Huynh-Feldt	1.342	48.000	.028					
	Lower-bound	1.342	24.000	.056					
trials	Sphericity Assumed	.145	9	.016	1.572	.125	.061	14.150	.729
	Greenhouse-Geisser	.145	4.204	.035	1.572	.185	.061	6.609	.483
	Huynh-Feldt	.145	5.207	.028	1.572	.170	.061	8.187	.546
	Lower-bound	.145	1.000	.145	1.572	.222	.061	1.572	.226

Error(trials)	Sphericity Assumed	2.215	216	.010					
	Greenhouse-Geisser	2.215	100.885	.022					
	Huynh-Feldt	2.215	124.977	.018					
	Lower-bound	2.215	24.000	.092					
emg * trials	Sphericity Assumed	.278	18	.015	1.477	.094	.058	26.585	.908
	Greenhouse-Geisser	.278	6.554	.042	1.477	.184	.058	9.680	.588
	Huynh-Feldt	.278	9.277	.030	1.477	.155	.058	13.702	.706
	Lower-bound	.278	1.000	.278	1.477	.236	.058	1.477	.215
Error(emg*trials)	Sphericity Assumed	4.523	432	.010					
	Greenhouse-Geisser	4.523	157.299	.029					
	Huynh-Feldt	4.523	222.659	.020					
	Lower-bound	4.523	24.000	.188					

a. Computed using alpha = .05

Appendix 4. EMG Averages for the Quadricep

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
emg	Sphericity Assumed	.136	2	.068	.764	.471	.031	1.529	.172
	Greenhouse-Geisser	.136	1.705	.080	.764	.453	.031	1.304	.162
	Huynh-Feldt	.136	1.822	.075	.764	.460	.031	1.393	.166
	Lower-bound	.136	1.000	.136	.764	.391	.031	.764	.134
Error(emg)	Sphericity Assumed	4.271	48	.089					
	Greenhouse-Geisser	4.271	40.927	.104					
	Huynh-Feldt	4.271	43.740	.098					
	Lower-bound	4.271	24.000	.178					

a. Computed using alpha = .05

Appendix 5. Conditions Vertical Jump Velocity at Takeoff Averages

Tests of Within-Subjects Effects

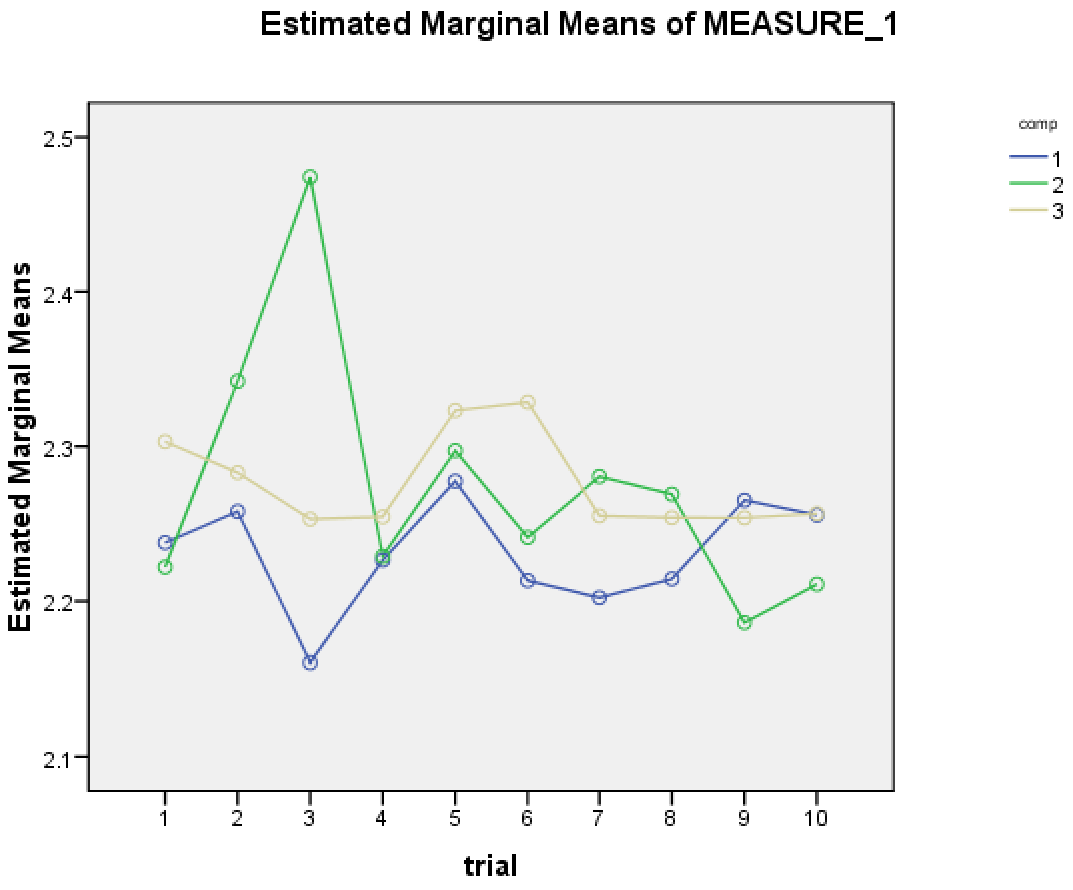
Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
comp	Sphericity Assumed	.334	2	.167	2.031	.142	.078	4.063	.399
	Greenhouse-Geisser	.334	1.849	.181	2.031	.146	.078	3.755	.382
	Huynh-Feldt	.334	1.996	.168	2.031	.142	.078	4.054	.398
	Lower-bound	.334	1.000	.334	2.031	.167	.078	2.031	.278
Error(comp)	Sphericity Assumed	3.951	48	.082					
	Greenhouse-Geisser	3.951	44.365	.089					
	Huynh-Feldt	3.951	47.903	.082					
	Lower-bound	3.951	24.000	.165					
trial	Sphericity Assumed	.448	9	.050	.727	.684	.029	6.545	.356
	Greenhouse-Geisser	.448	3.656	.122	.727	.564	.029	2.659	.217
	Huynh-Feldt	.448	4.394	.102	.727	.588	.029	3.195	.238
	Lower-bound	.448	1.000	.448	.727	.402	.029	.727	.130

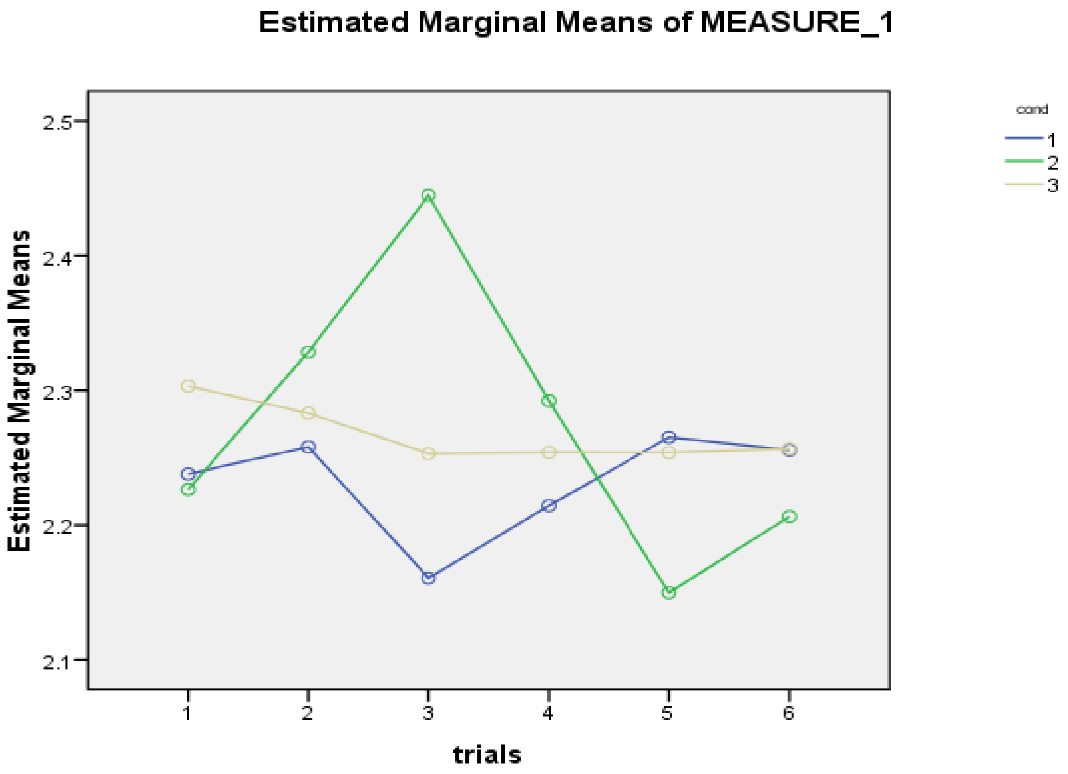
Error(trial)	Sphericity Assumed	14.780	216	.068					
	Greenhouse-Geisser	14.780	87.740	.168					
	Huynh-Feldt	14.780	105.460	.140					
	Lower-bound	14.780	24.000	.616					
comp * trial	Sphericity Assumed	1.616	18	.090	1.457	.101	.057	26.234	.903
	Greenhouse-Geisser	1.616	5.664	.285	1.457	.201	.057	8.255	.535
	Huynh-Feldt	1.616	7.614	.212	1.457	.179	.057	11.096	.631
	Lower-bound	1.616	1.000	1.616	1.457	.239	.057	1.457	.213
Error(comp*trial)	Sphericity Assumed	26.605	432	.062					
	Greenhouse-Geisser	26.605	135.937	.196					
	Huynh-Feldt	26.605	182.724	.146					
	Lower-bound	26.605	24.000	1.109					

a. Computed using alpha = .05

Appendix 6. Plot of Conditions Vertical Jump Velocity at Takeoff Averages



Appendix 7. Fatigability Plots based on velocity at takeoff



Appendix 8. Control versus Undersized Compression Maximal Voluntary Contraction EMG for Hamstring

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
trials	Sphericity Assumed	.289	3	.096	2.034	.130	.169	6.102	.469
	Greenhouse-Geisser	.289	2.343	.123	2.034	.147	.169	4.766	.405
	Huynh-Feldt	.289	3.000	.096	2.034	.130	.169	6.102	.469
	Lower-bound	.289	1.000	.289	2.034	.184	.169	2.034	.252
Error(trials)	Sphericity Assumed	1.420	30	.047					
	Greenhouse-Geisser	1.420	23.433	.061					
	Huynh-Feldt	1.420	30.000	.047					
	Lower-bound	1.420	10.000	.142					

a. Computed using alpha = .05

Appendix 9. Control versus Undersized Compression Maximal Voluntary Contraction EMG for Quadricep

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
trials	Sphericity Assumed	1.126	3	.375	1.954	.142	.163	5.863	.453
	Greenhouse-Geisser	1.126	2.089	.539	1.954	.165	.163	4.083	.365
	Huynh-Feldt	1.126	2.652	.425	1.954	.151	.163	5.183	.421
	Lower-bound	1.126	1.000	1.126	1.954	.192	.163	1.954	.244
Error(trials)	Sphericity Assumed	5.761	30	.192					
	Greenhouse-Geisser	5.761	20.892	.276					
	Huynh-Feldt	5.761	26.522	.217					
	Lower-bound	5.761	10.000	.576					

a. Computed using alpha = .05

Appendix 10. Control versus Undersized Compression EMG Averages for Hamstring

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
cond	Sphericity Assumed	.375	1	.375	4.759	.054	.322	4.759	.504
	Greenhouse-Geisser	.375	1.000	.375	4.759	.054	.322	4.759	.504
	Huynh-Feldt	.375	1.000	.375	4.759	.054	.322	4.759	.504
	Lower-bound	.375	1.000	.375	4.759	.054	.322	4.759	.504
Error(cond)	Sphericity Assumed	.788	10	.079					
	Greenhouse-Geisser	.788	10.000	.079					
	Huynh-Feldt	.788	10.000	.079					
	Lower-bound	.788	10.000	.079					

a. Computed using alpha = .05

Appendix 11. Control versus Undersized Compression EMG Averages for Quadricep

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power^a
cond	Sphericity Assumed	.004	1	.004	.127	.729	.013	.127	.062
	Greenhouse-Geisser	.004	1.000	.004	.127	.729	.013	.127	.062
	Huynh-Feldt	.004	1.000	.004	.127	.729	.013	.127	.062
	Lower-bound	.004	1.000	.004	.127	.729	.013	.127	.062
Error(cond)	Sphericity Assumed	.319	10	.032					
	Greenhouse-Geisser	.319	10.000	.032					
	Huynh-Feldt	.319	10.000	.032					
	Lower-bound	.319	10.000	.032					

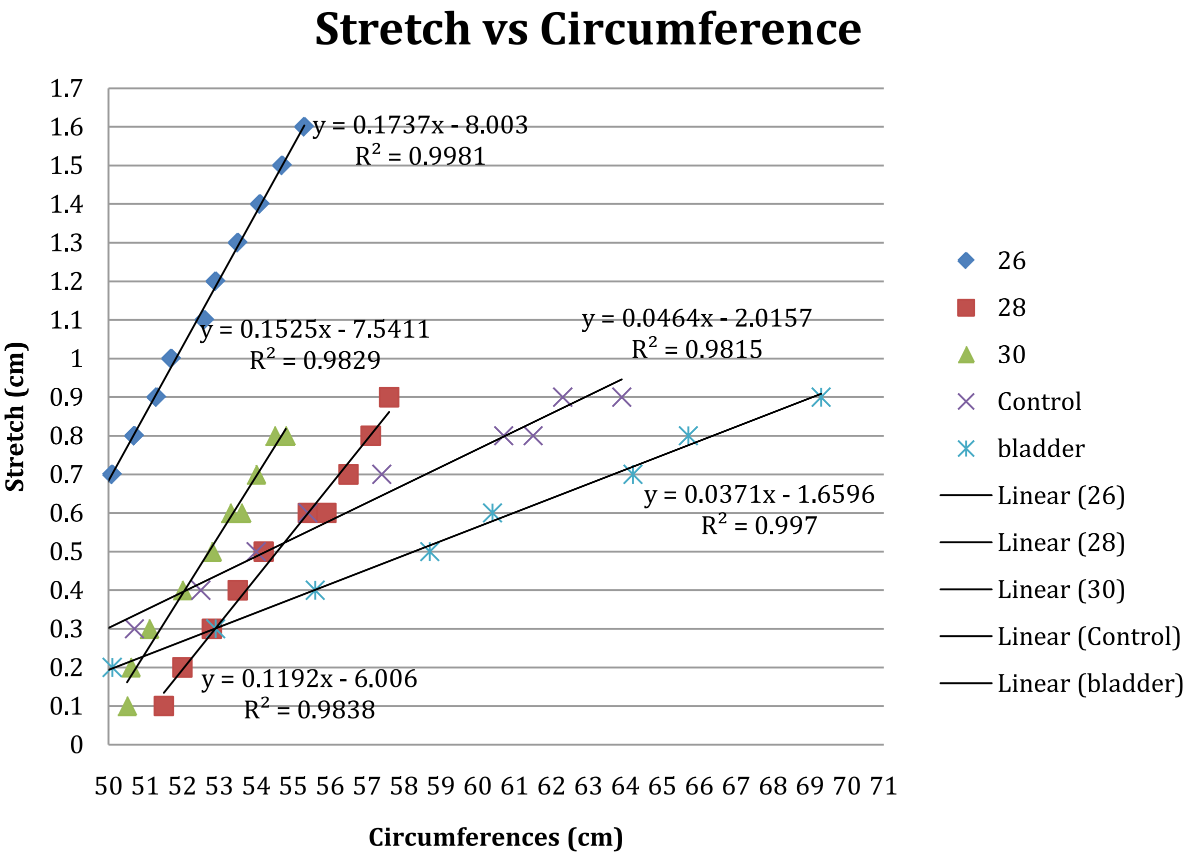
a. Computed using alpha = .05

Appendix 12. Control versus Undersized Compression Vertical Jump velocity at takeoff averages

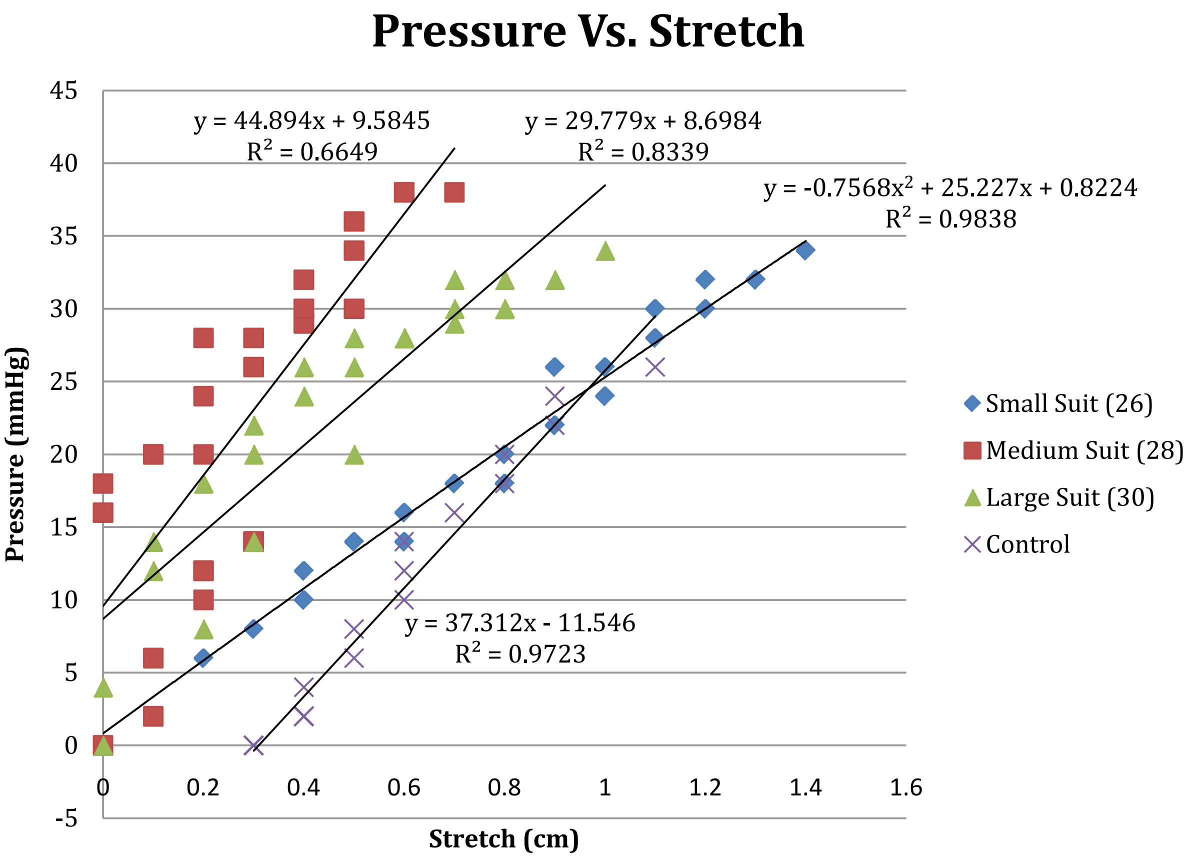
Paired Samples Test

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Control - Compression	.052757977	.274755592	.082841928	-.131825341	.237341295	.637	10	.539

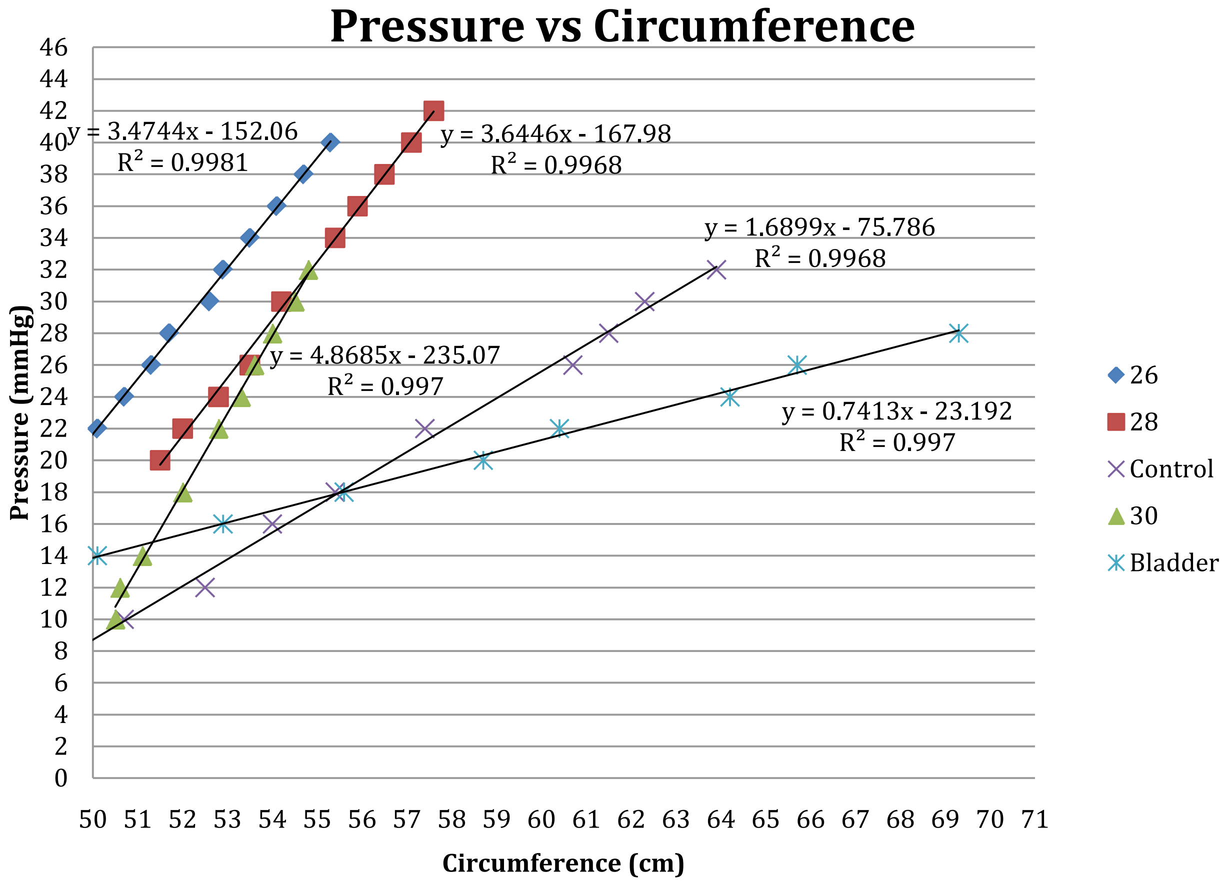
Appendix 13.) Suits Stretch versus Circumference Measurements



Appendix 14.) Suit Pressure versus Suit Stretch



Appendix 15.) Suit Pressure versus Thigh Circumference



Appendix 16.) Dimensional Measurements of Suits

	Undersized	**Regular Fitting**	**Oversized**
Waist Band (cm)	50.0	57.6	61.2
Mid Thigh (cm)	45.4	45.6	46.4
Lower Leg Band (cm)	34.3	34.5	35.7

Appendix 17.) Subject thigh circumference measures

Subject Number	**Circumference (cm)**
1	53±0.5
2	52±.04
3	51±0.2
4	53±0.3
5	51±0.5
6	51±0.2
7	51±0.4
8	52±0.2
9	51±0.1
10	52±0.3
11	51±0.5
12	54±0.1
13	52±0.4
14	53±0.2
15	53±0.4
16	51±0.1
17	53±0.3
18	54±0.1
19	52±0.4
20	53±0.2
21	54±0.1
22	52±0.1
23	53±0.3
24	53±0.5
25	52±0.1

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