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Title: Effects of a Seven-Week Practical Blood Flow Restriction Training Program on Lower-body Strength and Power

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The purpose of this thesis study was to examine the effects of a seven-week, practical blood flow restriction (BFR) training program used in combination with a traditional strength training program on measures of lower-body strength and power. The participants included sixty-two collegiate American football players divided into four groups. Three of the four groups completed a traditional upper- and lower-body split strength routine. Two of these three groups additionally completed supplemental lifting sessions. Of these two, only one group completed the additional lifts with blood-flow restricted. The final group of the three completed an altered training program, followed by the supplemental lifts, with blood-flow restricted. The supplemental lifting protocol included a barbell back squat exercise, comprised of a 20% 1RM load for four sets. The initial set encompassed 30 repetitions, followed by three additional sets of 20 repetitions each. All sets were separated by 45 seconds of passive rest. The supplemental squat was completed only at the conclusion of lower-body routines. Squat 1RM and vertical jump were utilized as the dependent measures of lower-body strength and power. Results of a 4 X 2 mixed model MANCOVA revealed a significant difference for the interaction on a single dependent variable. Follow-up univariate ANOVAs indicated a significant difference for 1RM squat. This suggests that a practical BFR training program used in addition to a traditional strength-training program can be effective at increasing 1RM squat performance, but not vertical jump. The use of elastic knee wraps makes BFR a feasible training option for coaches and athletes.

Keywords: KAATSU, occlusion, strength training, vertical jump

EFFECTS OF A SEVEN-WEEK PRACTICAL BLOOD FLOW RESTRICTION TRAINING PROGRAM ON LOWER-BODY STRENGTH AND POWER

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Introduction

Strength and power are important qualities in many athletic endeavors (Komi, 2003). Both of these qualities are components of the neuromuscular system and are related to one another. While optimal development of both of these characteristics does require specific training; in some sports, such as American football, the traditional approach is to focus more on the strength aspect as oftentimes, gains in power are seen concurrently, although often sub-optimal.

The traditional training methods employed to elicit strength gains generally include the use of heavy, acute loads and low repetition ranges. The American College of Sports Medicine (ACSM) and the National Strength and Conditioning Association (NSCA) recommend training loads >70**%** of an individual's one-repetition maximum (1RM) for multiple sets of six or less repetitions to stimulate gains in muscular strength and size (American College of Sports Medicine 2009; Beachle & Earle, 2008; Garber, Blissmer, Deschenes, Franklin, Lamonte, Lee, Nieman, & Swain, 2011; Kraemer & Ratamess, 2004). This repetitive, high-load type of training is often followed for days, weeks, and sometimes even months at a time, depending on the goals of the athlete, coach, or both.

While this manner of strength training can be effective, it can also place considerable stress on the body's muscular and skeletal structures (Smith, 2004). Consider a traditional strength set and repetition scheme for the barbell back squat: 5 sets of 4 repetitions (reps) with a barbell load of 100kg (220lbs). The load-volume total for this exercise alone would be 2000kg (4400lbs) (5 sets x 4 reps x 100kg), or nearly 2 metric tons. This load-volume is equal to a 2014 Toyota Tacoma double cab 4x4 with a

115-pound passenger sitting in the front seat (Toyota Motor Corporation, 2014). If this effort were to be repeated three times a week for one month, one can begin to understand the type of strain involved in eliciting progressive strength gains (ACSM, 2009; Kraemer & Ratamess, 2004).

However, high quantities of volume can be attained with other configurations of sets and reps. Recent research from Mitchell et al. (2012) and Ogasawara, Loenneke, Thiebaud, & Abe (2013) demonstrated significant hypertrophic musculature adaptations utilizing multiple sets (3-4) to volitional fatigue with low-magnitude loads of only 30% of 1-RM. Since the number of repetitions performed to reach fatigue can be quite high (e.g., >50) due to the lower acute load, the overall training volume can be comparable to traditional training schemes.

A unique variation of this high-repetition, low-load theme is blood flow restriction training (BFR). This type of training employs the same low-load, high-rep protocols, but couples it with the restriction of blood flow to the muscles being exercised. A significant advantage of utilizing BFR in addition with a high volume, low-intensity training protocol, is its ability to reduce the total volume and or time under tension required to yield muscle hypertrophy as compared to training with low-loads and to muscle failure (Loenneke, Wilson, et al., 2012). This small advantage may seem insignificant, however, when factors such as time and efficiency are of the essence (as in many strength and conditioning programs) to an individual’s profession, small advantages may result in improved results. Loenneke et al. (2012) also mention the added benefit of applying BFR training to those with special circumstances, such as the elderly or injured, who may not be able to sustain the mechanical stress involved with training to failure, in which BFR becomes a more reasonable and realistic training option.

In brief, the blood flow restriction is accomplished with the use of a wrapping device that is placed around the limb and is tightened just enough to occlude venous blood return from the muscle, but only restrict or reduce arterial blood delivery to the wrapped muscle. While seemingly counter intuitive, research has demonstrated this technique to be effective in eliciting gains in muscular size and strength across various populations and health conditions (Loenneke, Abe, et al., 2012).

While the majority of BFR research has been done in the laboratory or clinical setting, a recent study by Yamanaka, Farley, and Caputo (2012) has demonstrated this type of training to be effective among collegiate athletes in a free-living environment. Yamanaka et al. (2012) observed significant improvements in 1RM performance values for the back squat exercise within NCAA Division I (DI) football players when a supplemental, low-load, high repetition squat protocol using BFR was performed at the conclusion of the traditional strength workouts.

Studies such as this are the first steps in examining the potential for BFR to be successfully implemented among athletic populations. As yet, there have not been any investigations, to the knowledge of this author, that have examined whether a long-term supplemental BFR training program can result in concurrent increases in muscular strength and power. This paper will review strength training in its traditional sense, the mechanisms and applications of blood flow restriction training, and conclude with an examination and discussion of the results of a recently concluded BFR training experiment utilizing an athletic team, which specifically addressed the strength and power relationship.

Resistance Training

Resistance Training (RT) is defined as “a form of physical activity that is designed to improve muscular fitness by exercising a muscle or a muscle group against external resistance” (Esco, 2013, p. 1). This type of physical activity is popular in today’s society and can be seen in various settings throughout the country. Resistance training programs are implented throughout high schools, colleges, and professional athletics world-wide. Other venues which incorporate RT programs include rehabilitation centers, fitness industries, hospitals, educational institutions, and the military.

Research has demonstrated RT to be an essential aspect of living a healthy, productive, and pro-active lifestyle for the general population (ACSM, 2009; Garber, et al., 2011), and is a fundamental aspect for the cultivation of numerous athletic qualities desired in today’s sporting domain. Resistance training promotes the development of numerous physical characteristics including muscular strength and hypertrophy, improvements in speed and power, agility, neuromuscular coordination, and local muscular endurance (ACSM, 2009; Kraemer & Ratamess, 2004,). Though several models of resistance training exist, **strength training** is generally favored by coaches and athletes to elicit increases in muscular strength and power (Hori, Newton, Nosaka, Cowan, & Stone, 2005).

Strength Training Variables

While strength training can seem simple on the surface, properly designing a program for an athletic team can be rather involved. There are six training variables that must be taken into account: exercise selection, training frequency, exercise order, training loads and repetitions, volume, and rest periods (ACSM, 2009; Garber et al., 2011; Kraemer, 1983; Kraemer, 1984; Kraemer & Ratamess, 2004). A brief review of each, as they relate to strength training, is provided below.

Exercise selection. This variable involves the task of choosing the proper exercises, functional movements, and lifting techniques appropriate to the training process and outcome goals (Kraemer & Ratamess, 2004). Exercises can be classified into two categorial movements known either as *core* or *assistance exercises*. Core exercises are known to recruit one or more large muscle groups (e.g., chest, shoulder, back, hip, or thigh), and involve two or more primary joints (i.e., mulit-joint exercises) (Baechle et al., 2008). Core exercises should receive priority status when selecting exercises because of their direct application to the sport or training goal (Garber et al., 2011). It is important to understand that multi-joint movements require greater complex neural activation and coordination, due to larger muscle mass involvement and are more suitable to initiate muscular strength due to being able to employ heavier weights as compared to single-joint exercises (ACSM, 2009; Kraemer & Ratamess, 2004). Common core exercises for athletic strength training programs are the back squat, bench press and overhead press.

Once the core exericses have been determined, it is then imperative to integrate several assistance exercises to help promote general muscular fitness and or for rehabilitative and pre-habilitative purposes. Assistance exercises are generally single-joint movements such as biceps curls, abdominal crunches, and leg extensions which focus on specific musculature and require substantally less technical mastery (ACSM, 2009; Garber et al., 2011; Kraemer & Ratamess, 2004). Assistance movements promote the development of the core exercises, as well as provide a role in the prevention of injuries for muscle groups predisposed for injury (e.g., rotator cuff musculature, hamstrings, adductors, and lower-back).

Exercise order. This variable is closely related to exercise selection (Simão, Farinatti, Polito, Marior, & Fleck, 2005; Spreuwenberg et al., 2006). The proper ordering of exercises should reflect the consequences of how one exercise will affect the quality of effort or technique of another exercise. A study by Sforzo and Touey (1996) found a 75% decline in the performance of the core bench press exercise, and a 22% decrease in core squat performance when assistance exercises, (e.g. arm and leg extensions respectively) were performed first during the training session. Other studies have generated similar results when multi-joint core exercises (e.g., bench press, squat, leg press, and shoulder press) were performed after several assistance exercises stressing similar muscle groups (ACSM, 2009; Simão et al., 2005; Spreuwenberg et al., 2006).

The metabolic cost and the neuromuscular demand of exercises must be considered when deciding which exercise to complete early versus those later in the workout. The order should follow the sequence of larger muscle groups before small, core multi-joint exercises before assistance single-joint exercises, and high intensity before low-intensity movements. This will allow for the proper execution of the lift to be performed without sacrificing technique and performance due to fatigue from prior exercises (ACSM, 2009; Sforzo & Touey, 1996).

Training frequency. This variable is defined as the "frequency or distribution of training sessions" completed during a definite time period (Bompa & Haff, 2009, pp. 93-94). In athletics, coaches often have an Annual Plan, in which they strategize an entire year's worth of training. This plan is then broken up into several phases, or "macrocycles," which are periods of time lasting weeks or months in which certain goals are pursued depending upon time of the year and relation to the competitive season (e.g., pre-competition phase, in-competition phase, off-season, etc.). These macrocycles are then further subdivided into "microcycles" which are generally one-week periods of time during which a three to seven-day training regimen is planned (Bompa & Haff, 2009, p. 203). While there are countless ways in which a single week can be programmed, the training frequency will vary, again depending upon the macrocycle that the team is in. Research on American football training programs has shown that teams training four or five days a week generally achieved better results than those who trained either only three days or more than six days per week (Kraemer & Ratamess, 2004). These types of programs will often use some form of a "split" training routine alternating upper and lower body training sessions with 1-2 days of rest incorporated between training days of the same muscle group. An example would be a four-day routine consisting of a two-day split, in which upper body is trained on Mondays and Thursdays, and the lower body is trained on Tuesdays and Fridays. This allows heavy training days to be conducted consecutively, but yet allows two days of rest and recovery from each training routine (Kraemer & Ratamess, 2004).

Training load. This variable is most simply referred to as the amount of weight lifted or resistance used during a strength training exercise and is sometimes referred to as training intensity (Kraemer & Ratamess, 2004). There is a close relationship between the training load and the number of repetitions generally programmed for the training load.

Repetitions. Repetition-ranges are referred to as the number of times an exercise can be successfully completed in a given set or time period. Table 1 displays the specific loading and repetition schemes traditonally implemented to accomplish distinct training goals, and demonstrates that the relationship between training load and repetition ranges is inverse.

Table 1

Load and Repetition Assignments Based on the Training Goal

Training Goal	**Load (%1-RM)**	**Goal Repetitions**
Strength	≥85	≤6
Power (SE)*	80-90	1-2
Power (ME)*	75-85	3-5
Hypertrophy	67-85	6-12
Muscular Endurance	≤67	≥12

**Single Effort (SE)*
**Multiple Effort (ME)*

Table adapted from work by Beachle & Earle (2008)

As training load increases, the repetition range generally decreases, and vice versa. What can also be seen is that conventionally, training for strength is pursued with the use of a high training load and low repetitions.

Volume. This variable is also known as volume-load, and is a complete summation of the total sets, repetitions, and load completed through an entire training session (i.e., sets x reps x load). Simply put, volume is the total quantity of activity performed in single training session (Bompa & Haff, 2009). Volume can be adjusted by changing the number of exercises performed in a session, increasing training density, varying repetitions, and increasing or decreasing exerise sets (ACSM, 2009; Bompa & Haff, 2009; Garber et al., 2011; Robbins, Marshall, & McEwen, 2012).

When implementing volume protocols for strength training, higher volumes are eventually required for advanced improvements, but too much volume may lead to overtraining and a decline in performance. Research by Robbins et al. (2009) compared lower-body strength values (1-RM) after 6 weeks of training when three different volume-load strategies were implemented at intensity matched (80% of 1RM) loads. Volume conditions included 1) low volume (1-SET) 2) moderate volume (4-SET) and 3) high volume (8-SET). Results suggested that high volumes (i.e., >4 sets) are associated with enhanced strength development but that “moderate” volumes offer no advantage. This research demonstrates that in terms of strength development, high volume programs are superior to low volume programs when implemented with similar intensities. However, as briefly discussed in the introduction, some research has demonstrated that strength can be accomplished with the use low magnitude acute loads, coupled with high repetition ranges and sets (Burd, et al., 2010; Mitchell et al., 2012; Ogasawara et al., 2013). So it appears that while volume is important for gains in muscular strength, the repetitions and loads used to achieve those gains may not be as well understood as was once thought.

Rest Periods. Rest periods are specific time intervals of passive or active rest given between sets of subsequent exercise. The amount of time given for rest periods is metabolically specific and will have a strong influence on the overall training adaptation (Kraemer & Ratamess, 2004). The purpose of any rest interval is to allow or hinder the replenishment of proper energy substrates for the specific type of training at hand. In traditional strength training, when high training loads are used, rest periods of 2-4 minutes between sets of are commonly utilized. This allows for the anaerobic energy systems as well as the neuromuscular system to recover enough to be able to generate another high intensity effort. As with all training variables there are numerous ways to structure and implement rest periods to gain the acquired effect being trained for. Table 2 illustrates the various relationships between rest periods and particular training goal. However, as will soon be discussed, the use of BFR training implements rest periods that are contrary to those generally used with traditional strength training programs.

Table 2

Rest Period Assignments Based on the Training Goal

Training Goal	**Rest Period Length**
Strength	2-5 minutes
Power (SE)*	2-5 minutes
Power (ME)*	2-5 minutes
Hypertrophy	30 seconds – 1.5 minutes
Muscular Endurance	≤30 seconds

**Single Effort (SE)*
**Multiple Effort (ME)*

Table adapted from work by Beachle & Earle (2008)

Blood Flow Restriction Training Mechanisms of Action

The act of reducing the amount of arterial blood flow to working muscles, while simultaneously occluding the return of venous blood flow is a form of training traditionally known as KAATSU (Sato, 2005). Recently, it has come to be known more commonly as blood flow restriction (BFR) training (Fahs, Loenneke, Rossow, Thiebaud, & Bemben, 2012). To accomplish BFR, a wrapping device is placed around the most proximal end of the extremities being trained, for which restriction is desired. A majority of the research done with BFR utilizes some variation of a pneumatic wrapping device such as KAATSU Master (Sato Sports Plaza Ltd., Tokyo, Japan), or a modified blood pressure cuff. These types of devices allow for greater and more precise control of the amount of pressure applied to the area of occlusion. However, due to pneumatic devices being costly and unpractical outside of a lab or clinical setting, there has been minimal research done focusing on alternative methods to induce a situation of restricted blood flow. In 2009, Loenneke and Pujol proposed such an alternative method through the use of elastic knee wraps for BFR training (i.e., practical BFR), which creates a viable option that is fiscally appealing for general use among athletes and coaches. Since it is not possible to measure the pressure of an elastic wrap once it is in place, it was suggested that tightening the wraps snugly to a moderate perceptive pressure (e.g., a seven on a scale of zero to ten) would be sufficient. This protocol for applying the acceptable perceptive pressure has since been shown to be effective in occluding venous return while sufficiently reducing arterial delivery (Wilson, Lowery, Joy, Loenneke, & Naimo, 2013).

The ensuing reduced arterial delivery and cessation of venous return is believed to be responsible for many of the proposed mechanisms for the efficacy of BFR training in promoting muscular strength. Some of the most popular theories stem from the known reduced oxygen availability and metabolite accumulation in the affected muscles distal from the point of occlusion. This low-oxygen, high-metabolite environment has been demonstrated to increase the recruitment of high-threshold motor units (Takarada et al., 2000; Yasuda et al., 2009), which are typically only recruited under heaving loading conditions (Henneman, 1957; Sale, 1987).

Muscle Environment & Type II Fiber Activation

Muscle fibers are typically recruited in a systematic ordering of motor unit recruitment known as the size principle (Henneman, Somjen, & Carpenter, 1965). The motor unit itself is an anatomic component within the neuromuscular system, and is described as the functional unit of human movement (McArdle, Katch, & Katch, 2010). In brief, a motor unit is comprised of a motor neuron and the individual muscle fibers that it innervates (McArdle et al., 2010). The muscle fibers within a motor unit are homogeneous and being innervated by a lone nerve allows them to act together as a single unit. Motor units are often described relative to their fibers. For example, a "small" motor unit is typically made up of the smaller, slow-twitch Type I fibers, which have low thresholds of activation. Whereas a "large" motor unit consists of larger Type II fast-twich (FT) muscle fibers, and operate with high thresholds of activation.

The size principal describes the systematic recruitment of specific Type I and II motor units to produce smooth coordinated muscle action and functional movement, and the recruitment order runs from the smallest to the largest motor units (Henneman et al., 1965). Small motor units typically control light loads and fine motor movements. As external loads increase, or as motor movements become more rapid, progressively larger motor units will be recruited as necessary to meet the increased demands. This concept is significant because it demonstrates that fast-twitch fiber activation is coordinated through motor units with high activation thresholds (Cook, Clark, & Ploutz-Snyder, 2007), which generally predominate in anaerobic-type activities as are commonly seen in American football strength programs (e.g., jump squats, cleans and snatches) (Hori et al., 2005).

However, it has been shown that the size principle does not always function in this typical manner. In terms of the size principle, recruiting large and more difficult to excite motor units to produce maximal forces is only possible through the use of heavy loads. In the past, the philosophy of heavier-is-better to induce strength gains has been a favorite among authors and strength professionals; however, there is limited research to support this approach (Carpinelli, 2008). In the case of eccentric actions (Nardone, Romano, & Schieppati, 1988) and concentric actions under ischemia (reduced blood flow), FT fibers are recruited favorably even in the absence of a high external load. The latter situation is typical of low load BFR training sessions (Moritani, Michael-Sherman, Shibata, Matsumoto, & Shinohara, 1992; Sundberg, 1994; Takarada, Takazawa, et al., 2000). A current theory of why the size principle operates the way it does is based not off of the external load used to activate high-threshold motor units, but from the amount of effort required to sustain the force to resist external load (Carpinelli, 2008). Carpinelli stated that higher-threshold motor units are recruited systematically as the amount of "effort" increases throughout a single set of exercise, and not because of the quantity of increased load.

In Carpinelli's review of the size principle (2008) he gives a simple, but relevant example of how this understanding of increasing effort and supplying constant force is present during an isometric muscle action. If an individual holds a 20 kg dumbbell at an angle of 90 degrees in elbow flexion, the force of internal elbow flexor muscles is equal to the torque of the external force of the 20 kg dumbbell. For the initial time period, 10-15 seconds, this exercise may seem easy, however as 1 minute approaches, the exercise becomes increasingly difficult until maximum effort is required to sustain elbow flexion at 90 degrees. As initial motor units fatigue, higher threshold motor units have to be recruited to sustain the force required to maintain a 90-degree. There eventually becomes a point shortly after a minute where the individual will no longer be able to maintain the isometric muscle action at 90 degrees without maximal effort. Though heavier loads were never applied (the dumbbell load stayed at 20 kg), the recruitment of high-threshold motor units was required to sustain elbow flexion as long the individual could perform the action.

This example demonstrates that as the required effort increases, the larger and more difficult to excite motor units, are activated even though the external load was low-to-moderate in intensity and was never increased. The ability to train and produce forceful muscle actions, which rely heavily on anaerobic muscle, utilizing low-magnitude loads could be advantageous for athletes and coaches.

Blood flow restriction training has been shown to recruit fast-twitch muscle fibers with low loads, similar to how traditional strength training recruits FT fibers with high magnitude loads (Takarada et al., 2000; Takarada, Sato, & Ishii, 2002; Takarada, Takazawa et al., 2000). In a state of hypoxia (decreased oxygen availability), an environment with high metabolite (lactate) accumulation may occur (Schoenfeld, 2010). Hypoxia by occlusion method has been shown to increase lactate accumulation while concurrently reducing the rate of lactate clearance (Takarada, Takazawa et al., 2000). Decreasing the oxygenated arterial blood flow to working muscles constrains oxygen delivery, creating an anaerobic environment. Increased metabolite buildup and decreased clearance may induce cell swelling, another proposed mechanism for the effectiveness of BFR (Schoenfeld, 2010). The cessation of venous returns retains these metabolites, not allowing the blood to flow out of working muscles to clear metabolic by-products. This entire process creates an optimal environment to potentiate the recruitment of FT muscle fibers utilizing low loads (20% 1RM) (Moritani et al., 1992; Takarada, et al., 2000; Takarada, Takazawa, et al., 2000).

Growth Hormone

In addition to Type II muscle fiber recruitment in a high metabolic environment, some research has indicated that there can be an exaggerated growth hormone release following BFR training (Fujita et al., 2007; Pierce, Clark, Ploutz-Snyder, & Kanaley, 2006; Reeves et al., 2006; Takarada et al., 2000). Although the role played by systemic growth hormone in hypertrophy has been challenged in recent years (West & Phillips, 2010), its part in BFR should be taken into consideration.

Growth Hormone (GH) is an essential hormone in human growth and development, and assists in numerous physiological interactions within the body. Growth hormone, also called somatotropin is a polypeptide hormone synthesized, released, and stored in the anterior pituitary gland (Hoffman et al., 2009; Schoenfeld, 2010). Major physiological roles of GH within the body include linear growth and development, body composition alteration and metabolism, and anabolic tissue growth. Other interactions include hydration status, bone health, and cardiovascular function (Hoffman et al., 2009).

There are various avenues to stimulate the release of GH, which is released in a pulsatile fashion, rather than in a steady flow. Sleep, exercise, stress, nutritional intake, and heat can all affect the influence of GH release. However, in terms of this paper, we will only consider the ability of exercise to induce GH release. Particular protocols of exercise such as high volume programs with minimal rest periods can induce lactate accumulation and metabolic acidosis may ensue, which are associated with increased growth hormone release (Pope, Willardson, & Schoenfeld, 2013). This acidic environment is thought to be one of the main factors associated with the ability of BFR to produce hypertrophic and strength adaptations (Godawa, Credeur, & Welsch, 2012; Pope et al. 2013; Takarada et al., 2000; Takarada, Takazawa, & Ishii, 2000). Work done by Kreamer et al. (1990) has shown resistance training utilizing large muscle groups exercises, with 10-RM loads, for 3 sets of 10 repetitions, and rest periods of one minute or less can substaintially increase plasma concentration levels of GH.

However, the recruitment of fast-glycolytic fibers through high-resistance exercise and recovery periods is not necessarily the only way to induce a large metabolite accumulation. If muscles are forced to contract in a hypoxic condition where metabolite clearance is suppressed, an accumulation of metabolites will likely occur, and possible increased GH stimulation may result (Takarado, Nakamura, et al., 2000). This is the expected results when low-intensity exercise is combined with BFR. The combination of these factors makes the argument for the effectivness of BFR and the role GH may play in the deveopment of strength and hypertrophy through BFR.

Cell Swelling

The impact of metabolic acidosis, hypoxia, and GH release do not seem to account for all the conditions in which BFR has been shown to be advantageous. There have been several studies utilizing BFR that have included no exercise movements whatsoever. In 2000, Takarada determined that applying static BFR to incapacitated patients recovering from anterior cruciate ligament (ACL) surgery effectively offset the quantity of muscle loss during recovery. Due to being immobile, muscle recruitment was unnecessary and metabolic build-up would likely not occur. A similar study conducted by (Kubota, Sakuraba, Sawaki, Sumide, & Tamura, 2008) also demonstrated a reduction in the amount of thigh muscle atrophy in movement-limited participants receiving a BFR treatment.

Observations by Abe, Kearns, and Sato (2006) included an increase in muscular strength and hypertrophy by using BFR in combination with slow treadmill walking, which is considered a low intensity form of exercise (ACSM, 2010). Although Abe et al. (2006) did not measure metabolites, a similar study with comparable research was done in 2012 by Loenneke, Thrower, Balapur, Barnes, and Pujol in which lactate was assessed. Results indicated that even slow treadmill walking utilizing BFR did not result in metabolite accumulation. This demonstrates that while increased motor unit recruitment and metabolite build-up may play key roles in increasing strength and hypertrophy with BFR training, it seems likely that there are other mechanisms involved.

To compensate for continuing muscle adaptation without metabolite accumulation, it has been theorized that muscle **cell swelling** may be an important factor in BFR training (Loenneke, Fahs, Rossow, Abe, & Bemben, 2012; Loenneke, Fahs, Thiebaud, et al., 2012). Cell swelling serves as a major physiological regulator of cellular function, and has shown to stimulate anabolic processes (e.g., increasing protein synthesis) (Schoenfeld, 2010). Haussinger, Roth, Lang, & Gerok (1993) first theorized that cell swelling may induce an anabolic response, and follow-up work seems to support his idea (Berneis, Ninnis, Haussinger, & Keller, 1999; Keller, Szinnai, Bilz, & Berneis, 2003). Although the direct relation between cell swelling and anabolic tissue growth is yet to be determined, it is thought that increasing the pressure against the cell membrane (cell stretching) distresses its overall integrity, which may lead to an anabolic response to strengthen its ultrastructure (Schoenfeld, 2010). The decreased arterial delivery and lack of venous return during a BFR application leads to a pooling of blood in the muscles that are under conditions of occlusion. This pooling effect could cause a shift in cellular fluids leading to an increase in muscle cell volume (Schoenfeld, 2010). Another proposed mechanism of cell swelling and BFR to produce tissue growth is the process of “gradient-induced reactive hyperemia” (excess pooling of blood) after the removal of occlusion devices as the blood rushes back out of the occluded muscles (Nielsen et al., 2012). This situation may create cellular stretching and induce anabolic processes. These mechanisms may explain why BFR seems to slow down muscle wasting during times of immobilization when exercise and/or metabolite accumulation are not possible (Wilson, Lowery, Joy, Loenneke, & Naimo*,* 2013). Cell swelling might be the one constant variable across all methods of BFR training.

Blood Flow Restriction Training

Blood flow restriction training has shown its effectiveness for increasing strength in several populations (Loenneke & Pujol, 2009; Yamanaka et al., 2011). A 2012 study by Yamanaka et al. is one of the first studies to implement BFR within an athletic population. In addition to their regular off-season football strength training program, 32 NCAA Division I athletes completed four sets of supplemental bench press and squat, three days a week, for a total of four weeks (12 sessions) immediately after the completion of their regular off-season workout. The athletes were divided into 1) experimental (BFR intervention) or 2) control groups. Both groups completed four sets of supplementary bench and squat utilizing the following protocol: 1 set of 30 repetitions, followed by 3 sets of 20 repetitions with 45 seconds of rest inbetween sets. Each participant used a 20% load of their predetermined 1RM. The experimental group completed the protocol under conditions of blood flow restriction utilizing elastic Velcro wraps placed around the most proximal portion of the upper and lower body extremities. The wraps were worn on the upper extremities for the entire four sets of bench press, then switched to the lower extremeties to complete the squat exercise. The control group completed the same protocol without conditions of blood flow restriction.

Post-testing results showed signficant changes within both group for all measures of muscular strength. However, changes in 1RM values for bench press and squat were signifcantly greater in the experimental group than control group. The experimental group increased 1RM bench press by 9.3 kg and saw a 14 kg increase in 1RM squat values. Respectively, this resulted in a 7% increase in 1RM bench press strength and an

8% increase in squat strength as compared to the control group, who demonstrated strength increases of 3.2% and 4.9% (Yamanaka et.al., 2012).

The effectivness of BFR to increase strength has shown to be relevant with recreationally trained men, as presented in a six-week weightlifting study by Yasuda et al. (2011). Forty recreationally trained men were divided into four groups: 1) High-intensity resistance training (HI-RT) performed a free-weight flat bench press exercise for 3 sets of 10 repetitions at 75% 1RM, with 2-3 minutes of recovery between each set, three d/wk on Monday, Wednesday, and Friday. 2) Low-intensity blood flow resistance training (Li-BFR) also performed the bench press exercise, but completed 1 set of 30 repetitions followed by 3 sets of 15 repetitions at 30% 1RM, with 30s of rest inbetween sets 3 d/wk on Monday, Wednesday, and Fridays. 3) The combined group (CB-RT]) completed both the high-intensity training and low-intensity protocols. The CB-RT group completed the LI-BFR protocols on Mondays and Wednesdays, and completed the HI-RT on Fridays. 4) The control group (CN) completed no training. Results from this study showed that all three training groups increased 1RM bench press, while the control group showed no change. However, the percent change in 1RM strength was significantly greater in both the HI-RT and CB-RT groups at 10.5% and 6.7% as compared to the LI-BFR and Control groups, which saw percent changes in 1RM strength of 4.0% and 2.7% (Yasuda et al., 2011). This study revealed that the combination of BFR with high-intensity resistance training can significantly increase muscular strength.

Though more research is needed to verify the effectiveness of implementing a high-intensity strength program with low-intensity BFR to produce strength gains, the research available gives insight to the numerous possibilities that utilizing BFR and high-intensity programs together may have in future strength and conditioning programs.

Strength

Strength is a measure of human performance and a fundamental part of developing athleticism (Hori et al., 2005). Traditional training for muscular strength incorporates recruiting large motor units which engage Type II (fast twitch) muscle fibers, which are generally characterized by low aerobic capacity, high force/strength capability, and high motor-unit firing thresholds. Training for strength purposes predominatley includes moderate to large training volumes, high overall intensities, large muscle group exercises (e.g., bench, squat, clean), and extended rest periods of 2-5 minutes to allow suitable high energy substrate replenishment between sets (Beachle et al., 2008).

American football requires a considerable amount of physical strength to perform the duties required for individual positions effectively. Offensive linemen (OL) need to be able to push and pull an opponent to successfully block (the average bench press for DI OL is 160 kg or 352 lbs), while runningbacks (RB) need to be able to accelerate, change directions explosively, and run through defensive opponents (the average vertical jump for DI RB is 33.8 inches) (Garstecki, Latin, & Cuppett, 2004). Division I defensive linemen are typically some of the strongest athletes in American collegiate football, and have norm data values for bench press, squat, and power clean of 161.8 kg (356 lbs), 219.1 kg (482 lbs), and 133.2 kg (293 lbs) (Garstecki et al., 2004). As shown by these values, strength is an important component of American football, and highlights the focus of strength training in this sport.

Traditionally, strength training for American football players encorporates training with large muscle exercises such as squats, bench press variations, cleans, overhead presses, and other variations of Olympic lifts. Though every college strength program will have their own training philosophy and individual differences, the core lifts are generally programmed with an emphasis on strength, utilizing high-intensity loads (>80% 1RM), low-to-moderate training volumes (3-5 sets of 4-8 repetitions), and extended rest periods. Programs are typically linear (i.e., gradual increase in load as volume decreases) in nature, with various periodization techniques implemented throughout an annual training program to elicit specific characteristics of strength, power, speed, and hypertrophy to peak at specific times of the year. Football strength programs work around specific seasons (e.g., off-seaon, pre-season, and competition) and are directly related to the amount of sport specific training done concurrently with weight training.

The current study took place during the Emporia State University football program's off-season. The focus of the strength program was on developing maximal strength throughout the seven-week spring training period. This was done with the intention of devloping a base of overall strength, which could then be augmented and extended with an even more intensive strength and conditioning agenda in the summer off-season training program. The Emporia State strength program incorporates major lifts commonly seen in American football programs (e.g., squat, bench press, and overhead press), with lesser emphasis on Olympic lifting ability. Variations of Olympic lifts were typically implemented in moderate fixed-loads during dynamic and specific barbell warm-ups completed just prior to the high-intensity workout. These varations included power cleans and high clean pulls. Once the barbell specific warm-up was completed, athletes then moved onto the major strength core lift prescribed for the day (e.g., squat, bench press, or over-head press). Sets usually ranged anywhere between 3-6, with varying repetition schemes to elicit strength. Once the core lifts were completed, athletes then completed assigned auxillary lifts to supplement core lifts and assist in the stregnth development of smaller, indivdual muscle groups (e.g., biceps, triceps, calves, etc.). After all lifts had been completed, core exercises to strengthen the core and posterior chain were done as a team. A representative lower-body workout performed by Emporia State football athletes is presented in Table 3 in the Methods section.

Power

Power, a combination of strength and speed; can be defined in layman terms as how rapidly one can move a defined weight a set distance. Muscle power can be trained, and is an important parameter of success in different sports (Smilios et al., 2013). The NSCA defines power as the "time rate of doing work," work being defined as the product of force exerted on an object and the distance the object travels in a designated direction from which force was applied (Beachle and Earle, 2008). In short, power can be defined as how speedily one can lift, pull, and or push a set amount of weight through a defined range of motion.

Muscular power can be trained in many ways, with plyometrics and Olympic lifting (e.g., clean, snatch, jerk) being common among collegiate athletic programs. These exercises utilize the "triple extension" of the ankle, knee, and hip, which is an important aspect of many athletic power movements (May, Cipriani, & Lorenz, 2010). Exercises such as the clean, snatch, and jump squats are performed with high velocities to produce peak power production. In general, though there is much controversy on how much load to use, these lifts are performed with 0-60% of 1RM for 4-6 sets of 2-4 repetitions, and extended rest periods of 3-5 minutes (Smilios et al., 2013). May et al. (2010) stated that weightlifting is associated with the greatest increase in the rate of force development for two main reasons. 1) Weightlifting (Olympic cleans and snatches) assist in power production because of their intensity of the movement combined with resistance and 2) because these movements replicate the same triple extension complex involved in many power, jump, and sprint-like activities. Combinations of these training strategies are usually implemented in an American football-training program depending on the training cycle.

Strength, Power, and Blood Flow Restriction

While it is clear that the literature supports the efficacy of BFR training for promoting increases in strength across a variety of populations and modalities, it is less clear what effects BFR training may have on power output. There is research showing a positive relationship between strength and power (Adams, O'Shea, J.P., O'Shea K.L., & Cimstein, 1992; Baker, 1996; Stone et al., 2003; Young, Wilson, & Byrne, 1999). Knowing this relationship, it seems reasonable to suggest that an increase in one could potentially lead to an increase in the other. As the research discussed earlier has shown, BFR has the potential to increase strength. Therefore, increases in lower-body strength accomplished with BFR could also lead to increases in lower-body power, such as improvements in vertical jump performance.

There have been a few short-term studies examining BFR and power output. In 2005, Abe et al. examined sprint and jump performance in collegiate track and field athletes after an eight-day training program. Two groups were utilized during the study, 1) KAATSU training group and 2) control group. The KAATSU training group completed three sets of 15 repetitions with 30 seconds of rest between sets for both the squat and leg curl exercises at 20% 1RM, twice a day, for eight-consecutive days. In addition, they completed their normal sprint and jump training exercises. The control group completed the exact same jump and training practices, but did not participate in the supplemental lifting sessions. After the eight days of training, both sprint and power capabilities were tested for both groups. Post-testing results showed sprint performance only increased in the KAATSU training group as measured by the 30-meter dash, with the biggest increase occurring in the first 10 meters, which would seem typical from an increase in lower-body power. However, no changes in power were seen in the performance capability for either group in the standing jump, standing triple jump, or standing five jump tests.

More recently Cook, Kilduff, & Beaven (2014) investigated power output with trained athletes (semi-professional rugby players) on measures of sprint performance and countermovement jump power during a three-week training block. Two groups were selected from 20 trained male rugby athletes. One group completed standard exercises in conditions of intermittent BFR (restricted blood flow applied only during exercise, but not during rest periods) while the other group completed standard exercises without BFR intervention. Both groups completed three weeks of training, three days a week, for a total of nine sessions. Sessions included the standard exercises of leg squat, bench press, and weighted pull-up exercises for five sets of five repetitions at 70% pre-tested 1RM. Pre-test measures of speed and power included the 40-meter sprint and countermovement jump. Following the three-week pre-season training block, speed and power measures were again assessed for both groups. Though both groups observed positive increases in both power and speed, only the trained athletes in the BFR group experienced significant improvements in the 40-meter dash time (-0.4 ± 0.3%) and countermovement jump (1.8 ± 0.7%). These are two of just a few studies starting to show the capabilities of BFR to produce positive adaptations in power output.

Rationale for Present Study

The purpose of this study was to examine the effects of a seven-week, practical BFR protocol used in combination with a traditional weight training program on measures of lower-body strength and power using the 1RM squat and vertical jump (VJ) tests as dependent measures. This was a field experiment study conducted throughout the 2013 spring semester during the football team's scheduled off-season training, as a part of their overall strength and conditioning program. The study will help answer the question; will the implementation of a lower-body BFR strength-training program cause an increase in lower-body strength, and if so, will the increase in strength transfer to an increase in lower-body power?

Hypothesis

It was hypothesized that the group which completed the traditional training program, in combination with the supplemental lifting sessions, under conditions of practical BFR would experience greater gains in lower-body strength (1RM squat) and power (VJ), than those groups that did not.

Methods

Experimental Approach to the Problem

This study employed a pre-test, post-test mixed model design with a single training intervention. Participants were recruited from a mid-western regional university American football team, a National Collegiate Athletic Association (NCAA) Division II institution, from which 72 players volunteered to participate. All participants completed a seven-week, off-season strength and conditioning program encompassing exercises and training techniques traditionally implemented within collegiate football strength programs. Prior to the initiation of the training program, and again upon its conclusion, two dependent variables were measured: vertical jump performance and lower body strength as determined by a One-Repetition Maximum (1RM) parallel back squat.

Four groups of participants were constructed for the study. The football coaching staff was made aware that the experimental design required that one group's training program be modified in such a way that its members would not complete any high-intensity lifting (e.g., heavy back squats, power cleans, bench press, etc.). They expressed some concern about restricting specific positions whose on-field success is highly correlated to the expression of strength and power (linemen and linebackers), from completing these high-intensity exercises. To address this concern, the mentioned position players (linemen and linebackers) were removed from the initial selection pool, and the modified training group was formed from the remaining subset of players. Once the modified group was established, the linemen and linebackers were then returned to the selection pool with the other remaining players and randomly assigned among the other three training groups.

Participants

The football program was a part of the Intercollegiate Athletics Department at a mid-western regional university. Permission to conduct the study was granted by the university's Institutional Review Board (Appendix A). The coaching staff of the football team agreed to the recruitment of participants from the team, as well as allowing the necessary modifications to be made to the strength and conditioning program. Specifics of the study were verbally explained to the entire team during an initial team meeting. Seventy-two team members volunteered to be participants. Each participant signed an informed consent document (Appendix B). All were deemed healthy and able to train by the university's medical and athletic training staff.

The off-season training program took place during the spring of 2013 academic semester and lasted for seven weeks, with four training days per week – two upper-body days and two lower-body days. Players were assigned by their coaches to attend one of three training sessions each day, based on their class schedules. Training sessions were held at 7:15 a.m., 1:30 p.m., and 3:30 p.m.

The study began with 72 participants (18 in each group). Due to non-BFR related injuries or lack of compliance (absent from five or more BFR sessions) with the BFR training protocol, ten players were removed from the study. Complete data was collected on the 62 remaining participants (20.3 ± 1.1 years old, 99.1 ± 19.7 kg, and 7.1 ± 2.2 years of weight training experience).

Procedures

Pre-tests and Post-tests. All participants attended the pre-test and post-test sessions for assessment of dependent variables. Both the pre-tests and post-tests were conducted between two days. Pre-test day one consisted of the vertical jump test. This session was completed after 48 hours of rest. Pre-test day two followed the next day and consisted of the 1RM squat test. This order (VJ before 1RM squat) was put in place to ensure no muscle damage or soreness would affect either dependent measurement. The same measures were again taken at the post-test sessions, which were completed at the conclusion of the seven-week training program. Post-test day one took place after 48 hours of rest, followed by Post-test day two, taking place the very next day. All pre-tests and post-tests took place during the participants' regular training session time. Figure 1 provides a schematic of the testing and training sessions.

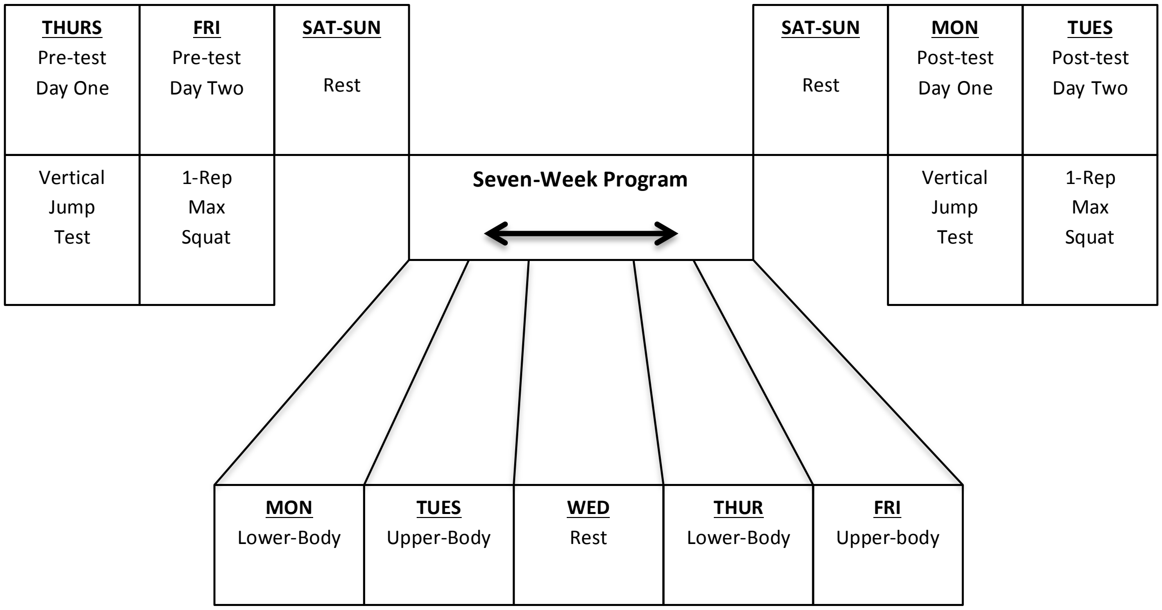

Figure 1.

Schematic of Study Implementation

Vertical jump. Lower-body power was assessed using the vertical jump test, measured with a commercial Vertec Jump Systems device (Vertec Jump Systems - Sports Imports, Hilliard, OH). The NSCA protocol for measuring vertical jump was utilized for assessing vertical jump performance for both pre- and post-test measurements (Baechle and Earle, 2008).

Two investigators were present at both the pre- and post-testing sessions. One investigator operated the Vertec jump system, while the other recorded the data.
After a uniform team warm-up consisting of general, dynamic, and specific exercises (See Table 3) the athletes were individually assessed on their vertical jump max. The primary investigator adjusted the height of the Vertec stack of movable color-coded horizontal plastic vanes to be within the athlete's standing reach height. The highest vane, which could be reached and pushed forward with the dominant hand while the athlete stood flat-footed, was determined as the standing touch height. The vane stack was then raised by a measured distance on the Vertec Jump Systems shaft supporting the vanes so the athlete would not jump higher or lower than the set of vanes. This required a rough estimate of how high the particular athlete would jump (position and athletic ability were taken into account). A corrected adjustment measurement was made (if necessary) for the second attempt.

Without a drop or stutter step, the athlete performed a short countermovement by quickly flexing the knees and hips, moving the trunk forward and downward, and swinging the arms backward. During the jump, the dominant arm reached upward while the non-dominant arm moved downward relative to the body. At the apex of the jump, the athlete tapped the highest possible vane with the fingers of the dominant hand. The

Table 3

Example of Dynamic Team Warm-up, Distance, Repetitions, and Duration

Exercise:	**Category**	**Distance**	**Repetitions**
Linear accelerations	Dynamic	20 yards	x2
Backpedal	Dynamic	20 yards	x1
Straight-leg bounds	Plyometric	20 yards	x1
Lateral shuffle	Dynamic	20 yards	x1
Carioca	Dynamic	20 yards	x1
Walking lunge	Dynamic	10 yards	x1
Reverse lunge	Dynamic	10 yards	x1
Lateral lunge	Dynamic	10 yards	x1
Free Body Weight Squats	Dynamic		x10
Good mornings	Dynamic		x10
Standing knee crossover	Dynamic		x5 each leg
Trunk twists	Dynamic		30 sec
Golf swings	Dynamic		30 sec

Warm-up was completed prior to each resistance training session and was never varied. Warm-up was completed in the same ordered sequence and format for both the pre-testing and post-testing vertical jump performance.

recorded score consisted of the vertical distance between the standing flat-footed vertical reach and the last vane tapped at the highest point of the vertical jump. The better of two attempts was recorded to the nearest 0.5 inches (1.27cm) (Baechle & Earle, 2008 Pg. 256).

Measurements for both pre- and post-tests, were taken by the same two investigators completing the same tasks for each testing session. Each are NSCA Certified Strength and Conditioning Specialists (CSCS).

1RM Squat. Maximal strength for the parallel back squat was assessed following procedures set forth by the football coaching staff. Players completed one warm-up set of ten repetitions utilizing approximately 40% of their estimated 1RM and a second warm-up set of five repetitions utilizing approximately 60% of their estimated max. After adequate rest, players loaded the bar with approximately 80-85% of their estimated 1RM and completed one repetition. Weight was then added with each subsequent one-repetition set until the player could no longer complete a repetition correctly. The 1RM was determined as the last weight utilized in which the participant successfully completed the lift with proper form through the entire range of motion, as defined by the NSCA (Beachle and Earle, 2008).

Conditions between the pre- and post-testing 1RMs were made as identical as possible. Wearing a weight lifting belt was encouraged, but not required. Players who decided to wear a belt for a pre-test 1RM also wore a belt for the post-test 1RM. The same was true for those who chose not to wear a belt. All 1RM tests, both pre and post, were supervised by the same members of our investigation team, each of whom is a NSCA Certified Strength and Conditioning Specialist (CSCS); Test-retest reliability as determined by our research team for the 1RM Squat was 0.35 % coefficient of variation.

Training Protocols and Groups

Each of the four groups completed a different training protocol and/or training intervention, an overview of which can be found in Table 4. Details of each can be found in Table 4 and examples of each can be found in Tables 4 and 5.

Table 4

Groups and Training Protocols

Group	**Modified Program (M)**	**Traditional High-Intensity Program (Tr)**	**Supplemental 20% 1RM Protocol (S)**	**Blood Flow Restriction (BFR)**
TrSBFR		✓	✓	✓
TrS		✓	✓	
Tr		✓		
MSBFR	✓		✓	✓

Table 5

Representative Lower-Body Day for Each Group: Total Volume-Load

Exercise	**Set**	**Rep**	**Load (kg)**	**TrSBFR Vol-Load**	**TrS Vol-Load**	**Tr Vol-Load**	**MSBFR Vol-Load**
Squat	1	8	130 (65%)	1040	1040	1040	
	1	6	140 (70%)	840	840	840	
	1	4	160 (80%)	640	640	640	
	1	2	170 (85%)	340	340	340	
	1	2	180 (90%)	360	360	360	
Lateral Squats	3	5	130 (65%)	1950	1950	1950	
Good Mornings	3	6	45.5	819	819	819	819
DB Lunges	3	8	22.7	544.8	544.8	544.8	544.8
Glute-Ham Raises	3	6	11.4	205.2	205.2	205.2	205.2
Supplemental Squats	1	30	40 (20%)	1200	1200		1200
	3	20	40 (20%)	2400	2400		2400
Total Vol-Load (kg)				**10339**	**10339**	**6739**	**5169**

Traditional Training Program. In brief, this was a weight lifting program focused on increasing strength. It included sets, repetitions, and traditional loading schemes of conventional high-intensity programs (i.e., several low-repetition sets with high %1RM loads). While the dynamics of the training programmed varied over the seven week period, its foundation was derived from lifts universally used in traditional American football strength and conditioning programs: bench press, overhead press, squats, and variations of each. Auxiliary lifts, such as bicep curls, triceps extensions, calf raises, and abdominal work were also included. Training frequencies were split into alternating upper- and lower-body days, each being trained twice per week, although not always in the same sequence. There were four training sessions per week, occurring on Mondays, Tuesdays, Thursdays, and Fridays. The training sessions were divided into two-day splits with a single day of rest provided on Wednesdays in between splits. Table 5 provides a representative workout session for lower-body training days. The program followed this lifting format for the duration of the seven-week training program.

Modified Training Program. This protocol was identical to the Traditional Training Program, with the exception that high-intensity squat and its variations were excluded (see Tables 4 and 5).

Supplemental Lifting Program. Participants completed these sessions together, at the same time, at the conclusion of their training workouts. The same two primary researchers supervised all sessions in order to ensure compliance. The supplemental squats were performed at the end of lower-body training days twice a week. Barbell load was set at 20% of pre-test 1RM. A list of each participant's barbell load was posted at each lifting station to ensure correct loads were used. Players completed one set of 30 repetitions followed by three sets of 20 repetitions, with 45 seconds of rest between each set (see Tables 4 and 5). The pace of the concentric and eccentric phases of each repetition was set at 1.5:1.5 seconds. This cadence was guided by a series of ascending and descending tones that were played through the weight room's stereo system from a pre-recorded .mp3 file. All four sets, including the rest periods, were incorporated into the .mp3 file as well as verbal instructions for the sessions. This provided consistency between all sessions throughout the duration of the program and allowed for the investigators to closely monitor the participants for compliance.

Practical BFR (occlusion treatment). Restriction of blood flow in the participants receiving the occlusion treatment was accomplished with the use of powerlifting elastic knee wraps with hook-and-loop closure (Grizzly Fitness, Kitchener, Ontario, Canada). The wrap dimensions were 7.6 x 167.6 cm (3.0 x 66.0 in), and were graduated every 1.3 cm (0.5 in) perpendicular to the edge with a silver permanent marker. For the BFR squat, the wraps were applied at proximal end of the lower extremities (at the top of thigh, near the inguinal crease). The wraps were initially applied without tension, but secure enough to remain in place. Just prior to the start of the lifting session, the wraps were pulled to a 7.6 cm (3.0 in) overlap as measured by the silver markings and secured. This tension was maintained for the entire four-set lifting session, including the rest periods. The wraps were removed immediately at the conclusion of the lifting sessions.

TrSBFR. This group completed the Traditional Training Program as well as the supplemental lifting protocol. They did so with the wraps in place, under practical blood flow restriction conditions.

TrS. This group completed the Traditional Training Program as well as the supplemental lifting protocol. However, they did not utilize the wraps; therefore they did not receive the occlusion treatment.

Tr. This group completed only the Traditional Training Program. They did not participate in the supplemental lifting sessions and at no time did they use the wraps.

MSBFR. This group completed the Modified Training Program. At the end of these sessions, they also completed the supplemental squat lifting sessions and did so under conditions of practical blood flow restriction with the elastic wraps.

Training Sessions. To accommodate players' class schedules, the athletes were assigned by their coaches to attend one of three training sessions each day. Members of each training group were present during all training sessions.

Participants did not wear knee or elbow wraps during the workout sessions**.** In addition, they were instructed to refrain from any resistance training outside of football practice for the duration of the study.

Statistical Analysis

A 4 X 2 mixed model MANCOVA, with training groups serving as the between factor, pre- and post-tests as the within factor, and body mass as the covariate was performed using PASW Statistics 18. The level of significance was set at .05. Separate univariate 1 X 4 analysis of variance (ANOVA) tests were conducted on each dependent variable as a follow-up test for any significant main effects from the MANCOVA.

Results

The means and standard deviations of the dependent variables are listed in Table 6.

Table 6

Descriptive Statistics

Dependent Variable	Group	Mean	Std. Deviation	N
Pre-test Squat	MSBFR	174.4	22.2	16
	TrS	196.7	27.6	14
	TrSBFR	193.2	25.0	17
	Tr	196.9	35.1	15
	Total	190.1	28.6	62
Post-test Squat	MSBFR	180.4	24.8	16
	TrS	210.9	26.8	14
	TrSBFR	218.1	24.6	17
	Tr	210.6	38.9	15
	Total	204.9	32.2	62
Pre-test VJ	MSBFR	80.0	7.7	16
	TrS	73.0	11.4	14
	TrSBFR	72.7	12.4	17
	Tr	70.6	11.9	15
	Total	74.2	11.2	62
Post-test VJ	MSBFR	81.5	7.2	16
	TrS	75.3	8.3	14
	TrSBFR	75.3	9.3	17
	Tr	73.7	13.2	15
	Total	76.5	10.0	62

MANCOVA results revealed a significant difference for the interaction on the dependent variables, Wilks' Λ = .744, *F*(15, 146.711) = 2.982, $p = 0.010$, multivariate ή2 = .138. To follow up the significant MANCOVA on the interaction, separate univariate ANOVAs were conducted on each of the two dependent variables. Only one of the follow up ANOVAs showed a significant effect. A significant interaction was found for 1RM squat, *F*(3, 57) = 6.460, $p = 0.001$, ή2 = .254 (see Figures 2 and 3). To help interpret the interaction, a one-way ANOVA was computed on the change scores for the 1RM squat. This ANOVA showed a significant difference between groups, *F* (3, 58) = 6.00, $p = -0.001$. Results of Fisher LSD post-hoc tests revealed that the TrSBFR group experienced greater gains in 1RM squat performance than did the MSBFR group ($p < 0.000$), the TrS group ($p = 0.025$), and the Tr group ($p = 0.009$).

Figure 2. 1RM squat performance change from pre-test to post-test measurements after the seven-week training program

** Significantly different from the other three training groups ($p < 0.05$).*

Figure 3. 1RM squat performance change from pre-test to post-test measurements after the seven-week training program

** Significantly different from the other three training groups ($p < 0.05$).*

MANCOVA results revealed no significant difference for the group factor on the dependent variables, Wilks' Λ = 0.808, *F*(15, 146.711) = 2.099, *p* = 0.059, multivariate ή2 = 0.101. MANCOVA results also revealed no significant difference for the time factor on the dependent variables, Wilks' Λ = 0.935, *F*(5, 53) = 1.944, *p* = 0.153, multivariate ή2 = 0.065.

Since the MANCOVA showed a non-significant main effect for Group, follow-up analyses were not required. However, to better understand how current results compare to lower-body power from practical BFR training and vertical jump performance, additional analyses were conducted on vertical jump performance.

For the vertical jump, dependent *t*-tests were run to examine changes from pre- to post test for the dependent variables and a 1 X 4 ANOVA was conducted on change scores. While the *t*-test on vertical jump revealed that there was a significant increase across groups (see Figures 4 and 5) [*t*(1,61) = -3.780, *p* < 0.000], the ANOVA did not detect differences between groups [*F*(3,58) = .406. *p* > 0.749].

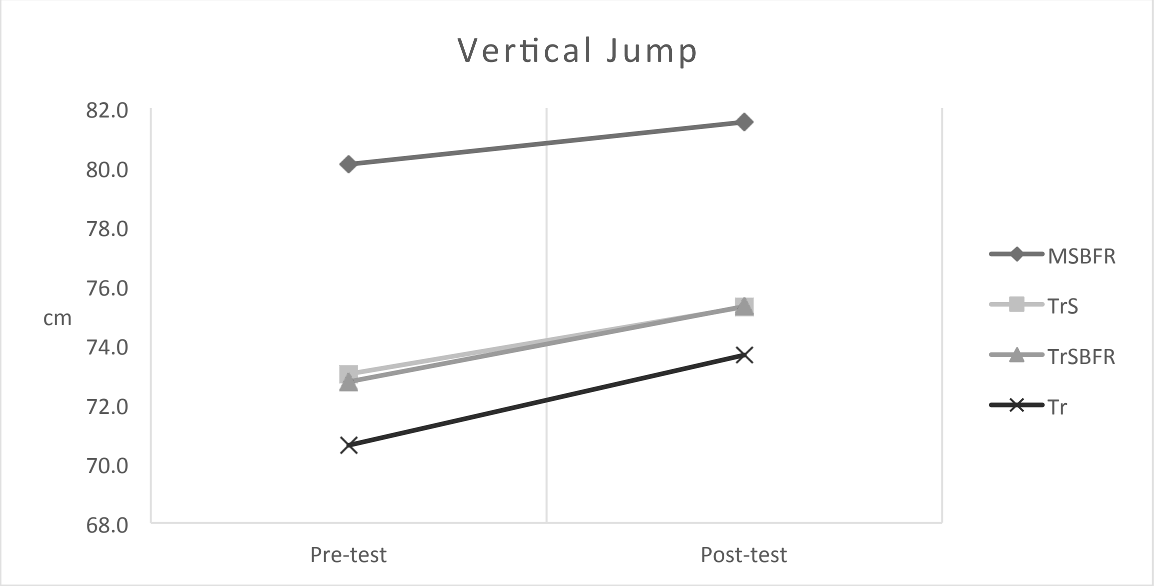

Figure 4. VJ performance change from pre-test to post-test measurements after the seven-week training program

All groups increased VJ performance, but no significant change among groups

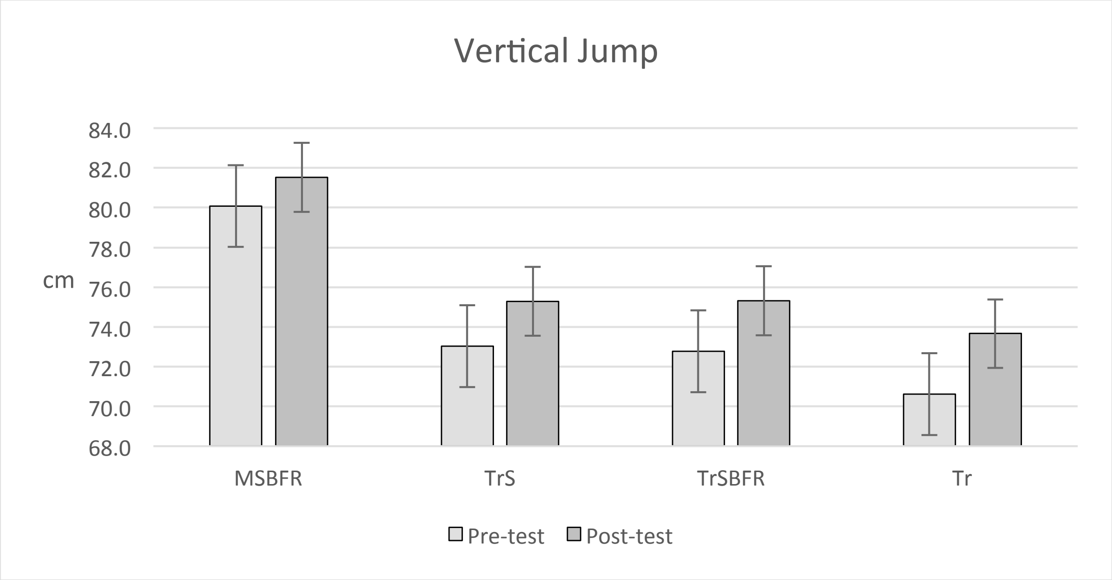

Figure 5. VJ performance change from pre-test to post-test measurements after seven-week training program

All groups increased VJ performance, but no significant change among groups

Discussion

The purpose of this study was to investigate the effects of a seven-week, practical BFR training protocol used in conjunction with traditional weight training on measures of lower-body strength and power in collegiate American football players. It was hypothesized that those who supplemented the traditional strength training program with the low-intensity lifting protocol under conditions of practical occlusion would experience greater gains in 1RM squat and VJ performance than those in the other treatment groups. The results partially support the hypothesis.

The primary results of this study were these: 1) TrSBFR experienced significantly greater increases in 1RM squat than the Tr, TrS, and MSBFR training groups, and 2) All groups experienced an increase in VJ performance, however, there were no differences in this improvement among the groups.

The supplementary low-intensity training protocol used in this study to examine the BFR treatment was a modification of that used by Yamanaka et al. (2012), who also utilized a collegiate American football team as the testing population. Both the Yamanaka study and the current investigation utilized a training load of 20% 1RM with a set and repetition scheme of one set of 30 repetitions, followed by three sets of 20 repetitions, with 45 seconds of rest between each set. The differences were that Yamanaka et al. (2012) used a 5.0 cm wide elastic wrap (manufacturer not reported) and tightened to a 5.1 cm [2.0 in] overlap, whereas we used a 7.6 cm wide wrap and used a 7.6 cm [3.0 in] overlap to achieve the BFR. They used a cadence of 2.0:1.0 seconds for pacing the eccentric and concentric components of each lift, whereas we utilized a cadence of 1.5:1.5 seconds, based on work by Yasuda et al. (2012). Also, they performed both the BFR squat and bench press on the same day, as their four-week program completed three total-body workouts per week. Our seven-week program utilized an upper- and lower-body split routine, with each being performed twice per week, for a total of four lifting days per week. Therefore, the BFR squat lifts were only completed on lower-body training days, following the respective lower-body workouts. Finally, their study utilized two training groups, both of which completed the supplementary 20% 1RM lifting sessions, although only one received the practical BFR wrap treatment. We replicated this scenario with our TrS and TrSBFR groups. However, we incorporated two additional groups in an effort to further clarify the potential effects of practical BFR training in a well-trained population.

1-RM Squat

Yamanaka et al. (2012) reported that the BFR treatment group experienced significantly greater gains in 1RM squat than those of the non-BFR control group. The current investigation replicated that finding. Univariate follow-up tests to the significant interaction showed a significant difference for squat (see Table 5). An examination of Figure 2 reveals that TrSBFR experienced greater gains than the other training groups

The gains seen by this group were likely the result of the use of practical BFR in conjunction with the low-intensity supplemental lifting protocol at the conclusion of the traditional high-intensity workout. A brief review of the training protocols helps explain this result. First, the MSBFR group also performed the supplemental lifts with the elastic wraps, but completed only the Modified Workout, which did not allow any traditional high-intensity squat variations. This seems to indicate that performing low-intensity BFR after high-intensity training results in greater increases than can be expected when performing BFR in the absence of high-intensity training, which supports the work by Yasuda et al. (2011). Second, TrS completed the high-intensity training and the low-intensity BFR protocol, but did not use the elastic wraps. Therefore, BFR appears to provide an additional stimulus for strength gains beyond the low-intensity supplemental lifting protocol even when used in conjunction with high-intensity training. Finally, the gains experienced by MSBFR and TrS were the same as those seen by Tr, who completed only the traditional high-intensity workout. Since there was no difference among these three groups, it is likely that the additional gains seen by TrsBFR are the result of the combination of the high-intensity training followed by low-intensity BFR supplemental lifting.

Vertical Jump

It was hypothesized that any increases in lower-body strength from BFR would be coupled with comparable increases in lower-body power. The current investigation did not support this hypothesis. Since the MANCOVA showed a non-significant main effect for the Group, follow-up analyses were not required. But as previously noted, additional analyses were conducted to better understand how current results compare to one another. While the dependent t-test on VJ revealed that there was a significant increase across all groups, the ANOVA did not detect any differences between groups. This indicates that in reference to lower-body power, neither the supplemental lifting protocol nor practical BFR application provided any additional benefit beyond what was experienced with the traditional high-intensity training regimen.

The occurrence that all four training groups experienced an increase in VJ is feasible since increases in lower-body strength (1RM squat) through the use of heavy loaded back squats has been associated with increase of peak power and VJ performance (Carlock et al., 2004; Cormie, McCaulley, & McBride, 2007; Gorugoulis, Aggeloussis, Kasimais, Mavromatis, & Garas, 2003; McBride, Triplett-McBride, Davie, & Newton, 2002; Moir, Mergy, Witmer, & Davis, 2011; Moss, Refsnes, Ablidgaard, Nicolaysen, & Jensen, 1997; Schimidtbleicher, 1992; Smilios et al., 2013; Stone et al., 2003; Young, Jenner, & Griffiths, 1998). Though power output as measured by VJ increased across all groups, the TrSBFR group, which had significantly greater gains in lower-body strength compared to the other groups, did not experience a significant increase in power production as hypothesized. The lack of power transference from increased lower-body strength to a direct increase in VJ performance demonstrates that the relationship between strength and power is not entirely linear. This has been demonstrated in research where increases in lower-body strength from heavy back squat did not result in a significant increase in lower-body power (Hanson, Leigh, & Mynark, 2007; Magnus et al., 2006; Scott and Docherty, 2004). Though research has shown increases in lower-body strength can increase vertical jump performance and power production, it appears there is a limit to the amount of translation of power output seen with further advancements in strength. There seems to be a point where power production plateaus with strength training and no longer increases without the implementation of specific power training exercises and protocols. Further increases in power necessitate increased specificity of training for power, such as complex training, where plyometric, Olympic lifts, and general strength training exercises are combined to produce peak power affects (Baker, 1996; Hansen and Cronin, 2009; May, Cipriani, & Lorenz, 2010).

Training Specificity

Specificity of training is the phrase used to to describe the select muscular responses and adaptations from particular styles of training. In other words, training adaptations are specific to the training stimulus applied for both acute programming and long term training. Physiological training adaptations are related to the type of muscle actions involved, the velocity of the movement, range of motion, muscles being trained, and energy systems being utilized (ACSM, 2009).

Specificity of training for sports is as varied as the field of sports itself. In regards to increasing power production, it has been shown that using a variety of training mechanisms (plyomtrics, Olympic lifts, and general strength exercises) is a popular method for improving peak power (Baker, 1996; Hansen and Cronin, 2009; May et al., 2010). Movements such as the jump squat, clean and jerk, and snatch are very effective at increase vertical jump performance due to thier similar firing patterns and the neuromusclar tasks as they relate to the vertical jump (Carlock et al., 2004). Examples of how specificity of training can induce greater increases in power are presented in two studies conducted by Hakkinen and Komi in 1985. In the first study (Hakkinen and Komi, 1985a) in which the electrical and mechanical behavior of leg extensor muscles during heavy resistance strength training was examined, VJ increased increased 10.6% through general strength training methods, utilizing heavy squats. However, in a follow-up study (Hakkinen and Komi, 1985b), VJ improved by 17.5% with the use of special training utilizing weighted jumps squats and specific plyometric jump training.

A recent study by Popovici (2013) demonstrated the effects of utilizing BFR with power specific exercise instead of strength specific exercises. In this investigation a

Wingate cycle ergometer was utilized to train and measure performance of peak power output among three groups: low-load only (45% Wingate resistance), low-load plus BFR (45% resistance + occlusion), and high-load only (95% Wingate resistance). After five weeks of training on the cycle ergometer (i.e., short interval, repeated maximal sprints), siginifcant increases in power were observed in both the load-load BFR group and the high-load group. This demonstrates that low-intenstiy BFR power training can elicit postive effects comparable to high-intensity, non-BFR power training. This is similar to what research has shown multiple times with strength training and suggests that BFR may have a place in power-specific training. In addition, this type of information is important for the athlete and strength coach as it further indicates that increases in power production are likely best experienced through a variety of power specific training methods.

The Emporia State football strength program, as mentioned before was focused on developing maximal strength during this phase of training, and lacked specific power exercises. Though two types of Olympic lift variations were implemented (power cleans and high clean pulls), they were not regularly implemented in a manner to produce continual adaptation, and instead were used for specific barbell warm-up purposes. This may help explain why the TrSBFR group did not see a significant increase in VJ power as expected with a greater increase in strength than the other training groups. The amount of power gained from increased strength was similar across groups. This suggests that at some time during the seven-week training period, a point was reached where the benefits of increasing power through increasing strength plateaued. To see further advances in power output, the addition of power specific exercises may have been necessary.

Limitations of Study

This study was not without limitations. As mentioned earlier, using elastic knee wraps limits the ability to determine the amount of pressure applied during BFR. (Manini and Clark, 2009). Wilson et al. (2013) have demonstrated that elastic wraps (7.6 cm wide) applied with a perceptive pressure of seven on a scale of zero-ten, is effective at allowing a restricted arterial flow while occluding venous return in the thigh muscle. In order to determine an average overlap we needed to find an appropriate perceptive pressure, by determining a common distance (cm) to overlap the wraps, which would supply sufficient pressure to a variety of individuals.

Everyone experiences similar situations differently. We understood that perceptive pressure is a subjective measure and would vary between individuals day-to-day. Yamanaka et al. 2012 used a 5.1 cm (2.0 in) overlap to achieve BFR in their study, but did not report on the procedure used to determine that degree of tension. Preceding the initiation of our training program, we recruited four athletes to assist us in the standardization of the elastic wrap pressure to be used in the study. We explained to them the concept of the zero-ten scale of perceptive pressure and how to use it in reference to wrap pressure (Wilson et.al., 2013). A wrap was then applied to the upper leg just tight enough to keep it from sliding down the thigh (this would be the initial pressure of zero). Next, the wrap was slowly stretched and pulled tight until the athlete indicated that the pressure had reach a perceptive pressure of seven. We took the difference of where the end of the wrap began and where it ended at the perceptive pressure of seven. We repeated this process with each athlete, requiring slightly different overlaps for each individual. The average of all the measurements from all four athletes was calculated and came out to be approximately 7.0 cm (2.75 in). We felt that an average overlap of 7.6 cm (3.0) would likely be sufficient for achieving a perceptive pressure of seven out of ten for most of the individuals participating in study.

Lastly, the participants in this study were well-trained, male, collegiate American football players. The results might not be generalizable to other athletic populations, non-athletes, or those who are weight-training novices.

Future Research

Future research should examine traditional high-intensity strength programs coupled with plyometric, special exercises (weighted jump squats), and Olympic lifts utilizing practical BFR to help determine the relationship between strength and power. This could provide additional insight into determining what type of relationship (linear or non-linear) does exist when the three are used in conjunction and if so, where the point of diminishing returns can be expected. If it is found that practical BFR, when used together with plyometrics, special training exercises, and high-intensity work, can elicit increased power output that are similar to, or exceed those typically observed with traditional high-intensity strength programs, then this could have implications for future program design. Together with an increase in strength, this could translate to improved athletic performance.

Investigating the type of relationship associated between BFR, general strength training exercises, and power specific exercises in the context of an in-season strength and conditioning program would be especially relevant. Typically, these programs reduce overall training volume and increase specific training and sport skills as focus shifts from developing strength and power capabilities to actual competition. This shift generally results in athletes experiencing declines in strength and power as the season progresses. An effective combination of plyometrics, special training exercises, and high-intensity work and practical BFR may result in the maintenance or increase of strength and power ability during the competitive season, which is typically not experienced.

Also, limb size and possibly body composition appear to play a role in how much pressure is needed to achieve adequate BFR (Loenneke, Fahs, Rossow, et al., 2012). Therefore, additional research should examine how to best individualize perceptive pressure when using practical BFR.

Practical Applications

The results of this study indicate that practical BFR training can be effective in increasing 1RM squat performance when added to an off-season, high-intensity collegiate American football strength and conditioning program, but was ineffective for increasing vertical jump. Elastic powerlifting knee wraps are relatively affordable and easy to use compared to traditional blood flow restriction methods. This reduction in the cost and complexity typically associated with BFR training provides athletic programs, teams, coaches, and athletes an increased opportunity to incorporate BFR into their strength and conditioning programs.

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APPENDIX A

INFORMED CONSENT FORM

INFORMED CONSENT DOCUMENT

Effects of a Seven-week Practical Blood Flow Restriction Training Program on Lower-body Strength and Power.

The Department of Health, Physical Education, and Recreation at Emporia State University supports the practice of protection for human subjects participating in research and related activities. The following information is provided so that you can decide whether you wish to participate in the present study. You should be aware that even if you agree to participate, you are free to withdraw at any time, and that if you do withdraw from the study, you will not be subjected to reprimand or any other form of reproach. Likewise, if you choose not to participate, you will not be subjected to reprimand or any other form of reproach.

Purpose: To examine the effects of a 7-week occlusion training intervention as well as changes in lower-body muscular strength and power.

There will be four groups of participants:

CON: Standard Workout - Occlusion Protocol - Occlusion

OCL1: Standard Workout - Squat + Occlusion Protocol + Occlusion

OCL2: Standard Workout + Occlusion Protocol - Occlusion

OCL3: Standard Workout + Occlusion Protocol + Occlusion

Brief Description of Sessions, Workouts, Occlusion Intervention, and Testing Measures:

Training Sessions Overview:

The training sessions and interventions will be performed during the spring off-season of the ESU football team Dependent variables will be measured prior to the start of the off-season training (Time 1) and upon conclusion of the off-season training (Time 2). The Occlusion Protocol will be performed at the end of the of each Standard Workout session, thus minimizing the effect of the protocol on the Standard Workout.

Standard Workout: The standard off-season strength & conditioning workout

Occlusion Protocol:

Performed at the conclusion of the Standard Workout

Squat: 1 set of 30 repetitions, followed by 3 sets of 20 repetitions, @ 20% 1-RM with 45 seconds rest between sets

Occlusion: Standard "powerlifting" elastic knee wraps with Velcro-style closure will be applied around the most proximal portion of the lower extremities just prior to the start of the Squat occlusion exercises and removed immediately upon completion of the exercises.

Risks and Discomforts: You will be performing exercise sessions that may lead to physical discomforts such as fatigue and/or nausea. Also associated with these tests are risks for other side effects that may include, but are not limited to, lightheadedness, muscle cramps, muscle strain and/or joint injury. You may feel delayed muscle soreness (24-48 hours) after exercise. You will likely feel very tired at the end of the sessions, but should recover within a few minutes.

Every effort will be made to minimize risks by careful observation during the sessions. There is a telephone available should a medical emergency arise, from which 911 and/or ESU Police & Safety will be contacted. If at any time you wish to stop, the session will be immediately terminated.

Testing Measures Overview

Dependent variables related to measures of lower-body muscular strength and power will include the squat 1-RM and vertical jump tests.

Testing Measures for muscular strength and power:

These tests will be conducted by a NSCA CSCS trained in these protocols.

Data will be collected two (2) times: just prior or to the start of the training program (Time 1) and again after the conclusion of the training program (Time 2).

See data collection overview and schematic below for detail.

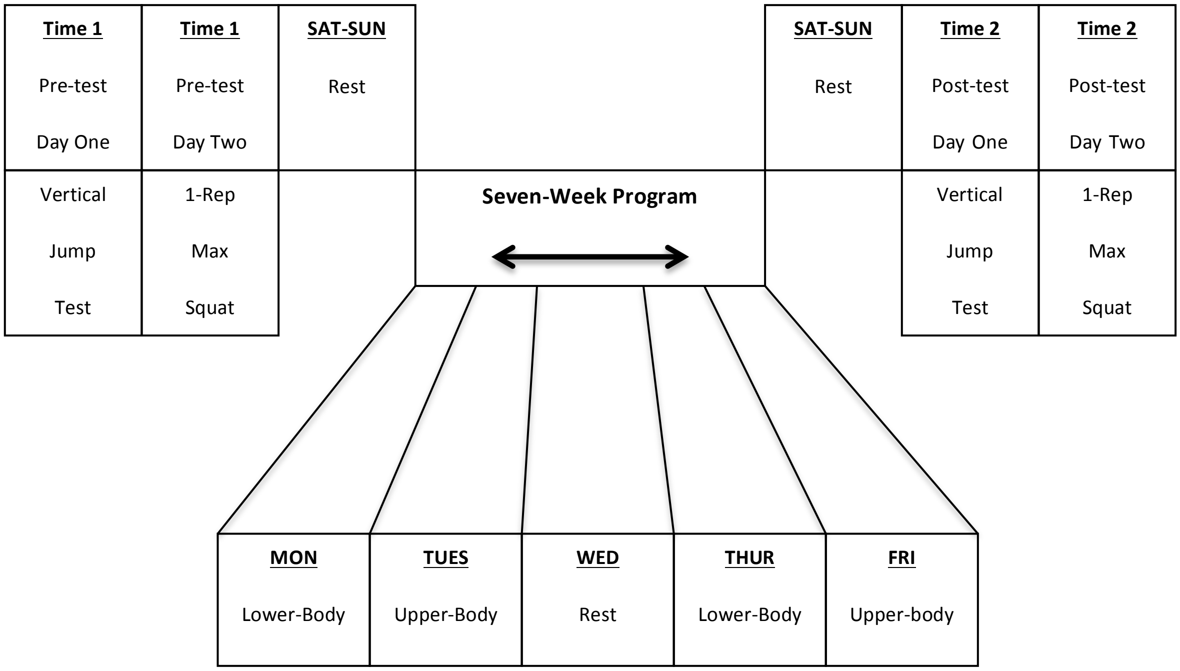
1-RM for Squat and Vertical Jump: assessed utilizing NSCA testing protocols

Data Collection Overview:

Measures for Strength and Power will be conducted two (2) times:

1) Time 1: one-two days prior to the start of the training program
2) Time 2: one-two days after the conclusion of the training program

Data Collection Overview Schematic:



Benefits: This study will help determine whether occlusion training in resistance-trained individuals is effective in stimulating lower-body muscular strength and power. If so, it could result in modifications to future athletic strength and conditioning programs. In addition, this study will provide you with an indication of your current level of muscular strength and power.

Compensation and Alternative: There is no compensation for participating in this study. You will have your test results explained to you. The alternative is to not participate in this study.

Confidentiality: Confidentiality of information about you gathered in connection with this study will be maintained in a manner consistent with federal and state laws and regulations. Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to you as an individual will not be disclosed. Your confidentiality will be maintained by assigning you a code number and by keeping all materials related to you locked in the Human Performance Laboratory or in the office of the Principal Investigator in the ESU HPER Building.

Do you have any questions at this time?

Questions: In the future, you may have further questions regarding this research project. Please contact Luke Kriley at 620-341-5954 or by email at lkriley@emporia.edu or Dr. Paul Luebbers at his office, via phone or e-mail: (620) 341-5653 pluebber@emporia.edu

"I have read the above statement and have been fully advised of the procedures to be used in this project. I have been given sufficient opportunity to ask any questions I had concerning the procedures and possible risks involved. I understand the potential risks involved and I assume them voluntarily. I likewise understand that I can withdraw from the study at any time without being subjected to reproach."

____

Participant name, printed

___________________________________ ____________

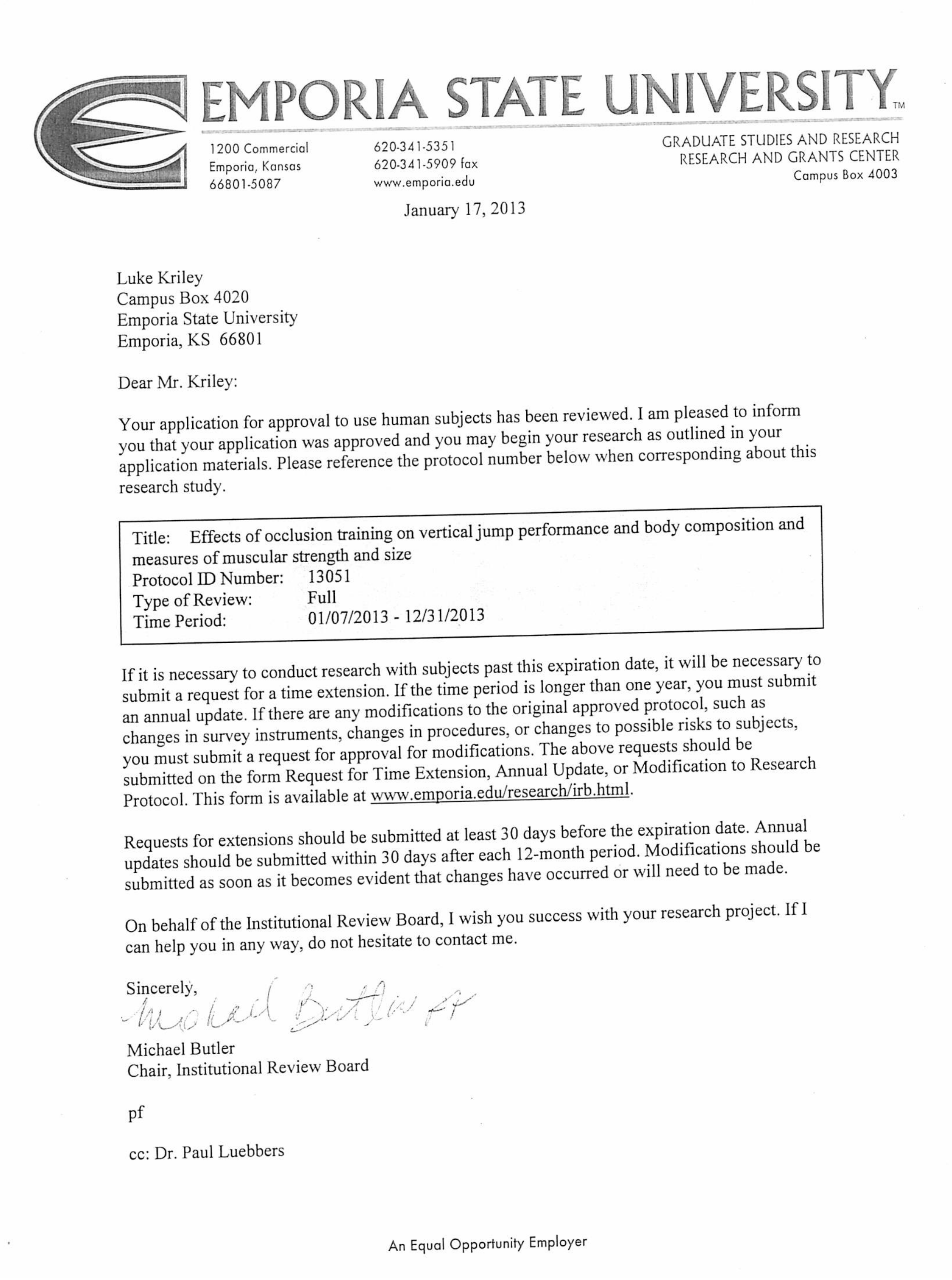
Participant signature Date

___________________________________ ____________

Investigator signature Date

APPENDIX B

IRB APPROVAL LETTER



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GRADUATE STUDIES AND RESEARCH
RESEARCH AND GRANTS CENTER
Campus Box 4003

January 17, 2013

Luke Kriley
Campus Box 4020
Emporia State University
Emporia, KS 66801

Dear Mr. Kriley:

Your application for approval to use human subjects has been reviewed. I am pleased to inform you that your application was approved and you may begin your research as outlined in your application materials. Please reference the protocol number below when corresponding about this research study.

Title: Effects of occlusion training on vertical jump performance and body composition and measures of muscular strength and size
Protocol ID Number: 13051
Type of Review: Full
Time Period: 01/07/2013 - 12/31/2013

If it is necessary to conduct research with subjects past this expiration date, it will be necessary to submit a request for a time extension. If the time period is longer than one year, you must submit an annual update. If there are any modifications to the original approved protocol, such as changes in survey instruments, changes in procedures, or changes to possible risks to subjects, you must submit a request for approval for modifications. The above requests should be submitted on the form Request for Time Extension, Annual Update, or Modification to Research Protocol. This form is available at www.emporia.edu/research/irb.html.

Requests for extensions should be submitted at least 30 days before the expiration date. Annual updates should be submitted within 30 days after each 12-month period. Modifications should be submitted as soon as it becomes evident that changes have occurred or will need to be made.

On behalf of the Institutional Review Board, I wish you success with your research project. If I can help you in any way, do not hesitate to contact me.

Sincerely,
Michael Butler pf

Michael Butler
Chair, Institutional Review Board

pf

cc: Dr. Paul Luebbers

An Equal Opportunity Employer

APPENDIX C

PERMISSION TO COPY STATEMENT

Permission to Copy Statement

I, Luke Kriley, hereby submit this thesis/report to Emporia State University as partial fulfillment of the requirements for an advanced degree. I agree that the Library of the University may make it available to use in accordance with its regulations governing materials of this type. I further agree that quoting, photocopying, digitizing or other reproduction of this document is allowed for private study, scholarship (including teaching) and research purposes of a nonprofit nature. No copying which involves potential financial gain will be allowed without written permission of the author. I also agree to permit the Graduate School at Emporia State University to digitize and place this thesis in the ESU institutional repository.

Signature of Author

Date

Title of Thesis

Signature of Graduate School Staff

Date Received