The Impact of Low-load Training with Partial Vascular Occlusion on Cycle Ergometer Peak Power

by

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ABSTRACT

Increases in fiber activation and muscle hypertrophy have been achieved with the use of low-load single joint resistance exercises in conjunction with partial vascular occlusion of the active muscle tissues, with subsequent increases in maximal voluntary contractions of 20-40% (Takarada, Sato, & Ishii, 2001; Takarada, Tsuruta, & Ishii, 2004; Sumide, Sakuraba, Sawaki, Ohmura, & Tamura, 2009; Leonneke & Pujol, 2009). Traditionally, similar gains in strength have only been elicited under conditions involving high-load resistance training (HL) at or above 75% 1RM (Sale, 1992; Baechle & Earle, 2008). The purpose of this study was to determine if partial vascular occlusion of working musculature during all out cycling on an ergometer would improve peak-power output, as measured during a Wingate Test. Subjects were separated into three training groups: A low-load occluded group (n=7), a low-load free-flow group (n=7) and a high-load free flow group (n=7). The low-load groups (LL and LLO) trained twice a week at 45% of the resistance used during their Wingate test, while the high-load group trained twice per week at 95% of the resistance used during Wingate testing. Training involved short sprint intervals at a maximum cadence ranging in time from 4 to 10 seconds per repetition, and 4 to 8 repetitions per session. After 10 training sessions, subjects in the LLO group and subjects in a HL group both improved significantly from pre to post testing in relative peak power (Watts/kilogram) by 14.4% and 14.1% respectively, while individuals in the LL group saw no significant improvement in relative peak power (4.6%). The LLO group improved significantly over the LL (*p* = .041), while the HL group's improvement, compared to the LL group, nearly reach significance (*p* = .082). Utilizing low-load training under partially occluded conditions during sprinting on a cycle ergometer results in significant improvement to relative peak power output.

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CHAPTER 1

INTRODUCTION

Increases in muscle hypertrophy and fiber activation have been achieved with the use of low-load resistance training in conjunction with partial vascular occlusion of the active muscle tissues (Takarada et al., 2001; Takarada et al., 2004; Sumide et al., 2007; Leonneke & Pujol, 2009). Traditionally, similar gains in strength have only been elicited under conditions involving high-load resistance training (HL) at loads equal to or greater than75% one-repetition maximum (1RM) (Baechle & Earle, 2008). Findings to date have demonstrated significant increases in muscle hypertrophy and electromyographic activity (EMG), with corresponding improvements in motor unit recruitment (Moritani et al., 1992; Moore et al., 2004; Lanza et al., 2005; Cook et al., 2007), and reduced instances of delayed onset muscle soreness (DOMS) (Wernbom et al., 2009) following training under occluded conditions at low-loads. All of these benefits are of certain intrigue to any power athlete and to rehabilitation specialists. It is then the goal of this study to explore some practical applications of vascular occlusion in conjunction with power training.

Statement of the Problem

Athletes in sports requiring speed and power continually seek the development of more sophisticated training methods to increase their force production. Rehabilitation professionals also seek ways to accelerate patients' recovery. Partial vascular occlusion combined with low-load dynamic exercise may provide a safe, and legal alternative, to achieve both of these ends when compared to traditional training and exercise.

Purpose

The purpose of this study is to determine if the use of low-load vascular occlusion training during dynamic, multi-joint exercise can improve peak-power output.

Hypothesis

The researcher hypothesized that low-load training with vascular occlusion and high intensity training during free-flow would both yield significant improvements in peak-power output after a six week training intervention, measured by a 30s Wingate test. A second hypothesis was that after six weeks, both of these programs will significantly improve peak-power output compared to low-load training during free-flow.

Delimitations

- The length of the training period was six weeks to account for the impact of an anticipated general acclimation to the training apparatus on results.
- The training protocols were designed to improve the acceleration period of the cyclist using short sprints lasting less than eight seconds throughout the training period with full recovery (6-8 times the length of each repetition).
- Subjects were untrained in cycling, which was considered less than 3 months of training specific to cycling.

Limitations

- During pilot study data collection, the researcher found that the quality of the blood pressure cuff systems could create slight variation in pressures between each individual cuff and each trial.

- The number of cycle ergometers and blood pressure cuffs is limited and did not allow for more than four subjects to be tested a time.
- It was observed that pressure could change during the pedaling exercises employed (up to $\pm$ 10 mmHg). The researcher accepts this variation, and, if needed, adjusted pressures immediately after each interval during training.
- Subjects were limited to seven per group after one was removed from each group for individual reasons which would have compromised the results.

Assumptions

- In the course of this study, it was assumed that all subjects are of a similar training background and of similar fitness levels based upon a brief survey.
- In the course of this study, it was assumed that subjects' body composition and muscle fiber make-ups are similar, both within and across the training groups.
- In the course of this study, it was assumed that all subjects were motivated equally during all sessions, and that subjects were pedaling at a maximum cadence and effort throughout all intervals, and pre and post testing.
- During post-testing, subjects were assumed to have a similar weight to their pre-test weight which would not change the resistance used during the post-test

Wingate Test and thus the same resistance was used during post-test Wingate data collection.

Definition of Terms

High-intensity/High-load	Exercising at loads close to maximum attainable levels. These loads are defined to intensities at, or above 75% of 1-rep-max.
Low-intensity/Low-load	Exercises at loads well below a maximum attainable level. These loads are defined to intensities at, or below 50% of 1-rep-max.
Low-load Occluded Exercise	Exercises performed with blood pressure cuffs attached to the proximal end of the working musculature with loads well below their maximum attainable levels. Typically these loads are set to intensities at or below 50% of max.
Partial Vascular Occlusion	Purposeful, partial blockages to vascular blood-flow, often through the use of a blood pressure cuff. Throughout this paper references to vascular occlusion will be to partial vascular occlusion unless noted.
Post-activation Potentiation	Increased force output following a previous

contraction; noted by greater electrical activity within a muscle during contractions.

Significance of the Study

This study provides a greater understanding into the dynamic possibilities of training with vascular occlusion. To date, the literature on this training modality has only examined occlusion training as an avenue towards increased muscle hypertrophy. The subject of using vascular occlusion during multiple joint dynamic exercise or power training remains to be fully researched or recognized. It is the goal of this study to establish whether vascular occlusion is a viable option for the development of peak power. As power is essential to the success of every athlete, any research confirming the possibility of different, yet practical training of a high-quality result would be of great significance to trainers, coaches and athletes.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

In the world of athletics, resistance training has been used for decades to improve strength, power, and coordination in the hope of improving overall athletic performance. Scientific research and trial and error have allowed the formation of well-established practical guidelines based upon specific physiological responses that are expected, almost guaranteed, under certain training conditions (Baechle & Earle, 2008). Traditionally, low-load resistance training (<50% of 1RM) causes increased local muscular endurance with limited gains in maximal force. Contrary to this, high-load resistance training (HL) (>75% 1RM) results in significantly greater force production and overall gains in strength, as a result of muscle hypertrophy, and improved neural recruitment patterns (Sale, 1992; Baechle & Earle, 2008). It has been observed that the magnitude of improvement during athletic performance is greatest when the actual training exercises performed closely resemble the movement patterns of the activity being tested (Sale, 1992).

In sports requiring short periods of great force, the greatest gains in performance can be expected when heavy resistance and specific movement patterns are used concurrently to stimulate higher threshold motor units, and elicit protein synthesis (Cook, Clark, & Ploutz-Snyder, 2007). During programs that continue over the span of months, or years, the ability of the athlete to respond to a training stimulus inherently decreases as a natural upper limit is approached, making creative and varied programs more successful over time to prevent this plateau (Sale, 1992).

With this in mind, it has been shown that large increases in muscle hypertrophy and fiber activation have been achieved with the use of low-load resistance training, in conjunction with partial vascular occlusion of the active muscle tissues (Takarada et al., 2001; Takarada et al., 2004; Sumide et al., 2007; Leonneke & Pujol, 2009). Similar gains in strength have only been elicited under conditions involving high-load resistance training at, or above 75% 1RM. Using single joint exercises of the leg and arm, many studies have examined the immediate and long-term muscle systems' responses both on a macroscopic and microscopic scale to ischemic conditions (Lanza, Larsen, & Kent-Braun, 2007). Findings to date have demonstrated significant increases in hypertrophy, (Kubo et al., 2006) and electromyographic (EMG) activity after training protocols (Moore et al., 2004). These findings have been attributed to increases in the subscription of muscle formation proteins, such as insulin-growth factor and human growth hormone immediately following bouts of occlusion training, resulting in greater muscle cross-sectional area compared to non-occluded groups (Cook et al., 2004). Some studies report increases in human-growth-hormone (HGH) as high as 290% compared to resting values following a leg-extensor exercise protocol with partial occlusion (Takarada et al., 2004; Leonneke & Pujol, 2009). Also, phosphofructokinase (PFK) activity has been higher in individuals during and immediately after cuff training (Sumide et al., 2007; Chiu, Wang,

& Blumenthal, 1976).

Improvements in muscle recruitment have also been proposed as a primary cause of strength gains after extended exposure to occlusion training (Moritani, Sherman, Shibata, Matsumoto, & Shinohara, 1992; Moore et al., 2004). This is of particular benefit to power athletes, as higher threshold motor units are recruited preferentially in force generation and in greater proportions. These adaptations have been documented with lower symptoms of DOMS than traditional hypertrophic lifting protocols and with lower proportions of eccentric muscle contractions, which are associated with DOMS (Wernbom, Järrebring, Andreasson, & Augustsson, 2009). There is an indication that the proportion of muscle fibers eliciting fast-twitch characteristics may increase over time, thus increasing the overall content of fast-twitch like fiber available to an individual (Lanza et al., 2007). All of these benefits are of certain intrigue to any power athlete and to rehabilitation specialists. It is of interest then to explore the practical applications of vascular occlusion in conjunction with power training.

Hypertrophic and Neural Adaptations to Various Intensities of Resistance Training

Improvements in performance as a result of strength training are most noticeably brought about through increased muscle hypertrophy, as greater muscle size leads to greater maximal force. However, this is not the only adaptation from resistance training which results in improved strength. It may not even be the mechanism primarily responsible for improved force output (Sale, 1992). In the first four to six weeks of a program, the nervous system and its ability to quickly adapt to training are largely responsible for improved performance (up to 25% increases in one repetition maximum (1RM)) with strength training (Baechle & Earle, 2008).

Resistance training is a skilled activity, and requires the development of particular motor patterns to complete the complex movements associated with it (Sale, 1992). The timing, speed and strength required to complete any task is dictated by the nervous system. Performing an act of strength is therefore no different than any other skilled action. It requires practiced communication between the central nervous system and the appropriate muscles. Therefore, we are presented two avenues to improve overall strength, neurological factors and increases in muscle hypertrophy (Sale, 1992). Yet, the extents of these adaptations to resistance training are directly related to the type, or style, of lifting utilized (Sale, 1992; Baechle & Earle, 2008).

Hypertrophy is the visible response to resistance training. The greatest gains in muscle growth are known to occur in a range of 65-80% of an individual's 1RM (Baechle & Earle, 2008). These adaptations are not as pronounced at lower loads (< 50% 1RM) (Jackson et al., 2007), or with resistances greater than 80% 1RM (Sale, 1992), as the total work performed fails to stimulate the release of large concentrations of the growth hormones responsible for large increases in hypertrophy (Tanaka & Swensen, 1998). Intensities above 85% 1RM primarily improve contractility and maximum force (Baechle & Earle, 2008), and while some hypertrophy is associated with this intensity, the rate of muscle growth is not as marked, as is seen with a resistance set between 65-80% of 1RM.

The more rapid rate of fatigue demonstrated at higher relative resistances produces a different primary adaptation. These high loads (>85% 1RM) train the central nervous system in the activation of high-threshold motor units, operating according to the size-principle, a step like process of recruiting larger motor units as intensity increases (Sale, 1992). At high loads a greater percent of a muscle is recruited by the nervous system, improving contraction strength. Individuals unfamiliar with intense resistance training often cannot activate fast motor units, recruiting only 40-60% of the muscle (Sale, 1992). Training intensities at near maximum-resistances requires the reorganization of the nervous system to allow the recruitment of high-threshold, high-energy motor units. As a result of a larger percentage of the muscle being active, there is an abrupt decrease in free ATP and PCr stores. This intensity cannot be maintained for long, as the glycolytic system cannot supply ATP fast enough for the intensity demanded by the neuromuscular system (Minahan & Wood, 2007). While time to fatigue is rapidly decreased, benefits from high-load/low-repetition training translate directly to increases in maximum force and power (Baechle & Earle, 2008). High-load training can also increase the firing rate of the involved motor units, allowing for a greater production in force (Sale, 1992).

Improvements of up to 25% in maximal force can occur quickly with the introduction of a new training stimulus (four to six weeks) as a result of neural adaptations from resistance training (Baechle & Earle, 2008). As noted, this is the result of faster firing-rates and an improved ability to recruit high threshold motor units (MU) within the agonist musculature (Sale, 1992). It is also the result of improved coordination, or motor learning, within the nervous system (Moritani, Oddsson, &Thorstensson, 1990) demonstrated by greater cooperation between multiple muscles, firing in precise moments, to increase force. With training, synergist and antagonist muscles are activated (or deactivated) more efficiently to complete the desired movements, resulting in noticeably better task-specific technique (Sale, 1992). This is supported by evidence that the CNS preferentially recruits specific motor units to improve the application of force (Grimby & Hannerz, 1976).

A preferential recruitment of fast motor units indicates that the nervous system can override the size-principle when performing tasks involving high force in a trained ballistic movement pattern. This adaptation is desirable in sports requiring great acceleration. Sale (1992) noted that training with high-velocity movement patterns increases high-velocity performance. Training examples of this are found in power lifting and plyometric strength training, both known to increase the rate of force production (Chu, 1996). Based upon this evidence, it appears the nervous system can learn to immediately activate fast-motor units over lower-force producing units. This is possible through high velocity training regardless of the level of resistance (Sale, 1992; Duchateau, Le Bozec, & Hainaut, 1986; Moritani et al., 1990).

Increased Reliance on Anaerobic Energy Systems during Ischemic Conditions

Studies investigating the effects of limited oxygen supply during exercise have increased steadily, including those examining resistance training with vascular occlusion

(Takarada et al., 2001; Takarada et al.,2004; Lanza et al., 2007; Cook et al., 2007; Sumide et al., 2007; Leonneke & Pujol, 2009). As evidence of its effectiveness as a training modality increases, occlusion training and its effects on special populations has grown in interest to researchers. To better understand these training effects, the body's response to acute local ischemia must first be understood.

Ischemia is a bodily condition in which there is an inadequate flow of blood to a tissue, often through a local blockage, resulting in greater demand for oxygen than there is supply. Occlusion is the act of purposefully creating a blockage to blood flow (BF), and it can be a complete or partial blockage. When such conditions exist, the affected tissues are forced to operate in a restricted system with limited oxygen. This prevents oxidative phosphorylation from fully contributing to meet ATP demand, impacting glycolytic flux and the time to fatigue at any intensity (Lanza et al., 2007; Cook et al., 2007). Slow-twitch fibers, which rely on aerobic processes for ATP production, must operate under a limited capacity during these conditions. In this restricted system, oxygen levels drop as blood pools, shifting energy supply towards the anaerobic systems.

One indication of this shift during ischemia is noted by phosphocreatine (PCr) levels *in vivo*, which are significantly reduced during occluded conditions, especially during a complete blockage (Chiu et al., 1976), and do not begin to replenish until normal BF resumes. Inorganic phosphate (Pi) and ADP levels rise in accordance with this drop in PCr, indicating a decreased capacity for the Alactic glycolytic system to produce ATP (Chasiotis & Hultman, 1983; Lanza et al., 2007). Glycolytic flux has been thought to increase during extended conditions of ischemia and during sub-maximal voluntary contractions with occlusion, as measured by increased lactate levels, decreased muscle glycogen(Chasiotis & Hultman, 1983), and increased PFK expression (Kawada & Ishii, 2008), indicating a greater use of type II fibers and fast-twitch motor units. This is likely the result of the inability of the muscle to recruit the oxygen dependent slow-twitch fibers (Cook et al., 2007). During complete vascular occlusion of the leg, Chasiotis and Hultman (1983) found lactate ([La+]) concentrations increased seven-fold and Pi levels increased three-fold during a forty-minute period of total occlusion. Muscle glycogen was broken down continually, while increases in Pi slowed after the first fifteen-minute interval of measure to a plateau, remaining there until the block was removed. As blood flow resumed and oxygen availability increased, Pi levels fell towards resting levels, as PCr levels began to rise.

The greater reliance on anaerobic glycolysis and fast-twitch fibers is also supported by Kawada & Ishii (2008), who found that two weeks after surgically crush-occluding venous flow from the hind-limb musculature of sedentary rats, occluded muscles increased in muscle glycogen content and resting [La+] levels. These concentrations increased significantly, near 40%, while muscle lipid density (a property of slow-twitch fiber) decreased 13%. Higher stores of glycogen in resting muscle are known as a property of fast-twitch muscle fibers. The researchers also analyzed myosin heavy chain isoforms, and found that the appearance type I fibers decreased by 5%, while type IIa decreased 3%, and type IIb increased 7% (SDS-PAGE staining). Muscle cross-sectional area (CSA) increased dramatically across all fibers as capillary density fell 25%. These results indicate that chronic occlusion can cause a shift in muscle fiber typing, away from the more oxidative type I fiber. One primary cause could be related to a rapid decline in contractility of slower-twitch oxidative fibers in the absence of oxygen. Also, the activation of larger motor units in the place of lower-threshold units made up of primarily oxidative fibers, could contribute to the inactivity of slow twitch fibers, leading to the reported adaptation (Kawada & Ishii, 2008).

Chui et al. (1976) demonstrated in dogs an increased involvement of the PCr and glycolytic pathways in energy supply, and a rise in Creatine-phosphokinase (CPK) levels in venous blood as a direct result of extended exposure to complete ischemia, measured through catheterization. High levels of CPK activity, an indicator of muscle damage often associated with resistance training, was noted after one hour of complete occlusion and resulted in symptoms of DOMS.

It has been demonstrated that under occluded conditions resulting in localized, limited BF, that a greater reliance is placed upon the anaerobic systems of the restricted tissues for the generation of ATP (Chasiotis & Hultman, 1983). A drop in PCr levels and increased glycolytic flux are responsible for this shift. Also, increases in resting lactate levels and a change in the concentrations of substrates within the occluded musculature (higher levels of AMP, ADP and Pi) indicate greater non-oxidative ATP production at sub maximal intensities (Chasiotis & Hultman, 1983; Lanza, Wigmore, Befroy, & Kent-Braun, 2005; Lanza et al., 2007). To further demonstrate an increased reliance on anaerobic systems during ischemic conditions, these metabolic effects noted in this section were all alleviated with the return of normal flow to the local tissues, with low instances of lasting effects, dependent upon the length of ischemic exposure and the extent to which BF was reduced (Chiu et al., 1976; Chasiotis & Hultman, 1983; Lanza et al., 2007).

Interestingly, the study conducted by Lanza et al. (2007) saw no shift in glycolytic flux during intermittent maximal isometric contractions with full occlusion compared to free-flow (FF) conditions. The researchers explained this through the specific methodology employed, which combined 12s isometric MVC under conditions of full occlusion. It was thought that the muscles in both conditions (FF and occlusion) were experiencing instances of flux near V_{max} due to the type, and length of the contractions, and due to the complete occlusion to flow, causing a buildup of glucose-6 phosphate, a known inhibitor to PFK.

Adaptations of Occlusion Training in Comparison to Conditions of Normal Blood-flow in Skeletal Muscle

Studies investigating the effects of low-load occlusion training indicate neuromuscular adaptations to contractility and an increased rate of muscle hypertrophy. This lies in opposition to the recommended NSCA resistance training protocols, and to the expected results for the loads employed, as a percentage of 1RM (Takarada et al., 2001; Takarada et al., 2004; Lanza et al., 2007; Cook et al., 2007; Sumide et al., 2007; Leonneke & Pujol, 2009). The mechanisms to elicit strength gain have been explored here and indicate that traditionally, high-load resistance training is associated with increased muscle hypertrophy and muscle activation (Baechle & Earle, 2008). Also, low-load resistance training is associated with an improved ability to buffer lactate and increase local muscular endurance at sub maximal loads, and not increases in maximal strength and CSA (Baechle & Earle, 2008).

For generations, Japanese martial artists explored occlusion training under the name of Kaatsu (Takarada et al., 2001). It began to gain notoriety in research studies in the late 1990s as a method to increase muscle size and strength at low loads. Low-load training is defined in the majority of the literature as 20-50% of 1RM, with the more recent studies using loads below 40% 1RM (Takarada et al., 2001; Takarada et al., 2004; Sumide et al., 2007; Leonneke & Pujol, 2009).

Training with partial occlusion at loads as low as 20% 1RM has demonstrated 10%-15% increases in muscle CSA after just 8-weeks, with strength increases of 10-20% of MVC (Takarada et al., 2001; Takarada et al., 2004; Sumide et al., 2007). Other studies have demonstrated gains in size and strength, after 2 weeks of training, equal to 12-14 weeks of traditional 70% 1RM training (Moore et al., 2004). This is due in part to increases in exercise induced anabolic hormones such as human growth hormone (HGH) and insulin growth factor hormones, which are secreted after intense exercise. Levels anywhere from nine-times those of baseline readings, and three-times those compared to traditional moderate to high-load training have been reported under conditions of low-load vascular occlusion training (Cook et al., 2007) and likely account for the rapid growth.

These protocols have been used with success in numerous populations, from college aged (Moore et al., 2004), to middle-aged (35-45 years of age) (Lanza et al., 2005), to older populations of women (50+ years of age) (Takarada et al., 2004). Populations of experienced athletes and strength-trained individuals have also all shown significant gains with low-load occlusion training (Wernbom et al., 2008; Takarada et al., 2001; Kubo et al., 2006). Rates of fatigue during these studies were faster under occluded conditions compared exercises performed during conditions of free-flow at the same intensity. This is expected from muscle tissue in a closed-system with limited oxygen availability (Lanza et al., 2007). Based upon the aforementioned results on occlusion training, studies appear consistent across various populations, suggesting occlusion training as a valid and reliable method to increase muscle size in healthy adults.

Beyond hypertrophic gains at low-loads, these occluded conditions produce increased muscle activation. Studies monitoring EMG response during occluded conditions have reported increased muscle activation at these low loads. Moritani et al. (1992) found increasing EMG activity in intermittent handgrip isometric contractions with partial vascular occlusion when compared to the same exercise under conditions of FF. Higher levels of EMG activity (both the frequency and amplitude of pulses) were found during the occlusion test compared to the FF controls. Also, for contraction sets that began under occluded conditions, and continued past cuff release, a spike in [La+] in the venous blood was noted almost immediately. Throughout reperfusion, [La+] and surface EMG activity increased with each contraction for the remainder of the test. This would indicate a progressive recruitment of motor units to maintain force during the test as lower threshold units fatigued. This evidence supports the theory that the type of muscle being recruited for activity is closely linked to energy state of the surrounding tissue. The availability of oxygen has a very causal relationship to the ability of the phosphocreatine system to recover both during, and after contractions. As a result of this, it is suggested that not just force and speed of contraction influence high threshold motor unit activation, but also the availability of oxygen (Moritani et al., 1992).

Evidence that activation of higher threshold motor units occurs during low-load vascular occlusion is supported by recent research which reports increased levels of glycogen stores post-occlusion training and higher levels in venous lactate immediately following cuff-release in the occluded group compared to control groups(Takarada et al., 2001; Takarada et al., 2004). Studies have also demonstrated increased muscle fatigue, as a measure of decreased ATP concentrations within test groups following isometric exercise utilizing complete occlusion, when compared to free-flow exercise of the same workload (Lanza et al., 2005; Lanza et al., 2007).

The most recent published study investigating partial vascular occlusion in combination with low-load training is by Wernbom et al. (2009). Unilateral knee-extensor exercises were performed at 30% 1RM for both legs for three sets, until failure within each set. For each subject one leg was selected randomly for occlusion, while the other remained as a FF control. Results indicate concentric EMG activity was not significantly different between legs, but repetitions to failure performed were 33% lower in the occluded leg compared to the FF leg. It was also reported that eccentric EMG activity was significantly lower during contractions in the occluded leg, and subjects reporting significantly lower symptoms of DOMS during occluded training supported this. These results are supported by Moore et al. (2004), who reported a significantly reduced resting-twitch torque and significantly greater post-activation potentiation (PAP) in muscles trained with vascular occlusion. Consequently, these studies indicate a decreased expression of muscle electrical activity prior to contractions in antagonist action following occlusion training as well as increased PAP, adaptations most commonly noted as effects of plyometric and explosive training.

As by-products of metabolism ([La+], ADP, Pi) pool within the active muscle, there is an increased dependence on higher and higher threshold motor units to maintain force output until complete fatigue. This is noted by the aforementioned evidence of increased EMG activity at low loads, reported and observed fatigue (Wernbom et al., 2009), alterations in substrate appearance, and ATP to ADP ratios. A greater activation, as a result of increased neuromuscular activity, is a possible cause for the extensive adaptations seen under partial vascular occlusion at low loads and the literature indicates it could result in intriguing applications to improvements in time to maximal force, or rather acceleration training.

High-Velocity Training with Partial Occlusion & Its Impact on Power

Changes to muscle firing rates and the formation of task-groups, expressed through learned movements, are essential elements of the specificity of training principle in athletics. Sale (1992) discusses how the processes of neuromuscular interaction utilized during training dictate the adaptations seen (i.e. the rate of force development). Moritani et al. (1992) and Moore et al. (2004) found that training under conditions of vascular occlusion could result in altered motor unit firing rates and recruitment patterns. These studies also suggested that fast-twitch MUs might become preferentially recruited over slow twitch MUs during periods of reduced blood flow, or oxygen restriction. This phenomenon also occurs during the execution of high-velocity movements under conditions of free-flow (Sale, 1992). Duchateau et al. (1986) and Moritani et al. (1990) found that preferential recruitment of the gastrocnemius, a predominantly fast-twitch muscle, was demonstrated over the soleus at higher pedaling speeds and during hoping, respectively. Bercier et al. (2009) noted a shift from large spatial recruitment to a preferential recruitment of fast-twitch fiber groups in the vatus lateralis of cyclists during six-second all-out sprints as velocity increased. Taken in combination, strength training must be specific to the desired movement patterns and velocities in order to maximize strength gains (Sale, 1992).

Studies examining the effects of occlusion training have primarily used single joint isokinetic and isometric exercises. It is of interest to examine the effect of occlusion training toward more sport specific applications, such as increased power output in high-speed movements. It has been understood that improved contractility and force rate development can occur with low-load resistance training under vascular occlusion. Sumide et al. (2009) following a low-load partially occluded training intervention on knee-extensors, demonstrated a significantly greater increase in force rate development during and isokinetic test at an angular velocity of 180°/s compared to lower speeds tested (60°/s and 120°/s). Results were attributed to the principles of specificity in training and the methodology of the training, which involved extensor exercises at contraction speeds nearest to those seen during the 180°/s test. Similar effects to high-speed free-flow training have been illustrated with high-speed occluded training (Ishikawa, Sakuraba, Sumide, & Maruyama, 2005).

Results from Takarada et al. (2001) also illustrate that the training protocol used during occlusion training has specific training effects. Elite rugby players conducted isotonic knee extensor exercises at a cadence of two seconds per contraction at 50% 1RM for three sets until failure. Post-testing revealed significant increases in strength at angular velocities of 30, 60 and 180°/s from pre-testing, but 30°/s increased significantly over all other velocities tested. The length of contraction time during training was very similar to this length of contraction during the 30°/s isokinetic test, which would explain the result. The authors comment that type II fibers were likely preferentially recruited during blood flow restriction, resulting in increased glycogen storage and improved glycolytic capacity, both adaptations in power trained individuals.

Kubo et al. (2006) demonstrated changes in tendon tension as a result of resistance training with high loads versus low loads under occlusion. Significant increases in CSA and MVC was seen in both groups, but an increase in tendon tension was only seen within the high-load resistance group. No change in tension was found in the occluded group, suggesting improved elastic properties in tissues following occlusion training compared to traditional high-load resistance training.

Minahan et al. (2008) revealed that high intensity resistance training of eight weeks improved peak power output in elite cyclists. This would indicate improved EMG activity and motor unit recruitment as a result of high load training, or a greater improvement in force development of recruited fibers, or both. In either case, the result would be more force production leading to a greater peak power output for each individual, compared to eight weeks prior. Subjects were able to improve their time to exhaustion during testing at the same work rate. The authors suggest that this was due to improvements in neuromuscular activity resulting in increased maximal force, and thus sub-maximal exercise time to exhaustion increased.

Based on the findings of these past studies, a study examining changes in peak power output after cycling under occluded conditions is of warranted interest.

Selecting Pressures and Intensities for occlusion training

Low to moderate-intensity exercise (20-50% 1RM) with vascular occlusion has recently been shown to have similar increases in muscle hypertrophy and strength compared to traditional high resistance training. Some of these studies have even reported that light intensity walking with partial occlusion can lead to hypertrophy in leg muscles (Sumide et al., 2009). These reports make low load training under conditions of limited blood flow intriguing to study, yet the optimal pressure for occlusion has yet to be established as it has yet to be explored thoroughly in the literature. Patients in past studies have complained of numbness and discomfort when using pressures greater than 180mm Hg. Sumide et al. (2009) investigated four different cuff pressures in an attempt to isolate the ideal pressure range for maximal gains in strength with the least discomfort. Twenty-one participants distributed across four groups of different pressures (0, 50, 150, 250 mmHg) were used in the eight-week study. Pre and post testing measured maximal isokinetic contraction in concentric knee extension at 60°/sec and 180°/sec. A Borg rating scale of perceived exertion (RPE) was used to determine subject discomfort and effort, and cuffs were removed immediately after exercise. Pulse wave amplitude was measured during occlusion in each group, and pre and post MRIs estimated changes in extensor CSA.

Results show RPE diminished across all groups over eight weeks, graded from the lowest to the highest level of occlusion. Concentric contraction strength at 60°/sec increased in all groups except for the 0 mmHg group, but not significantly. Concentric contraction strength at 180°/sec improved significantly in 50mmHg, 150mmHg and 250mmHg groups and total work (noted by the researchers as subjects' anaerobic capacity) significantly increased in the 50mmHg and 150mmHg groups. No significant increases in CSA were found. In the discussion the authors assert that affects were seen in as low a pressure cuff value as 50mmHg, and that in a separate study by the same authors, this pressure demonstrated increased EMG activity using a 40% 1RM range.

Cook et al. (2007) examined multiple resistances and pressures to also establish the most effective combinations to use when conducting training with vascular occlusion. Using a total of eight protocols, researchers measured fatigue as a percent reduction in MVC from the first contraction of the first set, to the last contraction of the third and final set during knee extensor exercise. The authors examined 20% and 40% of 1RM with complete or partial occlusion, and continuous, or intermittent inflation of the blood pressure cuff, and compared these to a high-load protocol using a load of 80% 1RM for the same exercise. They found that all of the continuous pressure protocols elicited statistically the same amount of fatigue as the high-load protocol, with the 20% continuous, partially occluded protocol having a statistically greater effect than the high-load protocol. No subjects complained of discomfort at pressures below 200mmHg, and there were no reported lasting side effects. Based upon these two studies, and Wernbom et al. (2009), it can be established that partial occlusion training is a relatively safe procedure when conducted with pressures below 200mmHg for time periods of less than one hour of continuous occlusion. Since occlusion training has lower instances of DOMS compared to traditional training, it is perhaps safer when these tested methods are adhered to.

Validity of the Wingate Test for Peak Power Measurement

Bercier et al. (2009) established that there is a strong relationship between cycling velocity and the recruitment of fast MUs during 6-second all-out sprints on cycle ergometers. As velocity increased from the first contraction to the seventh contraction, EMG activity during each contraction remained high. The width of each burst decreased compared to the previous as torque decreased with gains in pedal speed. This, along with fatigue to high threshold fibers and a depletion of PCr stores, result in a peak in power by the third contraction of each leg, with a subsequent and continuous decline with each contraction thereafter. In relation to the measurement of peak power with the use of a Wingate test, this study supports the idea that peak power occurs during the first 5second interval of an all-out cycling test.

MacIntosh, Rishaug, & Svedahl (2003) examined the effects of accounting for different resistances and starting techniques, as well as accounting for the moment of inertia. Their testing determined that higher values for peak power could be obtained with beginning the test from a standstill, versus a flying start, or by involving a rapid load application system. This is likely due to the time to peak power being increased during a flying start, as it takes longer to decelerate the flywheel with the addition of resistance to optimize the speed for peak power output. The authors suggest that beginning the test from a standstill, or decreasing the wind-up phase to two to four seconds will improve the validity of the results.

Summary

It has been shown that the use of low-load resistance training in conjunction with partial vascular occlusion of the active muscle tissues can cause large increases in muscle hypertrophy, and fiber activation. Traditionally during training these gains have been elicited under conditions involving high-load resistance training (HL). Using single-joint exercises of the leg and arm, studies have examined the immediate and long-term muscle systems' response to ischemic conditions on a macroscopic and microscopic scale. Findings to date have demonstrated significant increases in hypertrophy (cross-sectional area) and EMG activity after occlusion training protocols (Moritani et al., 1992; Takarada et al., 2001; Moore et al., 2004; Takarada et al., 2004; Lanza et al., 2005; Cook et al., 2007; Sumide et al., 2009). These findings have been attributed to increases in the subscription of muscle formation proteins, such as insulin-growth factor and human growth hormone well beyond resting values (Takarada et al., 2000; Takarada et al., 2001; Takarada et al., 2004), with improvements in muscle recruitment, supported by evidence that higher threshold motor units are recruited sooner (Cook et al., 2007; Sumide et al., 2009), and in greater proportion after cuff-training (Moritani et al., 1990; Moore et al., 2004). Also, PFK activity is higher in individuals during and immediately after cuff training compared to controls (Chiu et al., 1976; Lanza et al., 2005).

These adaptations have been documented with lower symptoms of delayed onset muscle soreness (DOMS) than traditional hypertrophic lifting protocols and as indicated by Wernbom et al., (2009), with lower proportions of force and EMG activity during eccentric muscle contractions, which are associated with DOMS. A shift has also been noted in the proportion of slow-twitch fiber to fast-twitch fiber over time, with an increase in the percentage of Type IIb fibers expressed in muscle exposed to ischemic training (Madarame et al., 2008). All of these benefits are of certain intrigue to any power athlete and especially to rehabilitation specialists. It is of interest then to explore the practical applications of vascular occlusion in conjunction with dynamic exercise aimed at improvement in peak power output.

CHAPTER 3

METHODS

Introduction

Increases in fiber activation and muscle hypertrophy have been achieved with the use of low-load single joint resistance exercises in conjunction with partial vascular occlusion of the active muscle tissues, with subsequent increases in maximal voluntary contractions of 20-40% (Takarada et al., 2001; Takarada et al., 2004; Sumide et al., 2009; Leonneke & Pujol, 2009). Traditionally, similar gains in strength have only been elicited under conditions involving high-load resistance training (HL) at or above 75% 1RM (Sale, 1992; Baechle & Earle, 2008). The purpose of this study was to determine if partial vascular occlusion during dynamic, multi-joint exercise on a cycle ergometer would improve peak-power output, as measured during a 30-second Wingate Test. It was hypothesized that after a 6 week training intervention, 1) low resistance training under conditions of vascular occlusion would be as effective as traditional high resistance training in improving cycle ergometer peak-power output and 2) that both of these methods would improve peak power significantly over low resistance training without any interruption to blood flow.

Participants

After gaining IRB approval for these methods, twenty-four SUNY Cortland students with limited cycling experience were recruited to participate in a 6-week, 12-session training program designed to measure changes in power output. Limited cycling experience was defined as less than 3 months of cycling training. Subjects were informed of all procedures and risks and provided written consent and were cleared to participate using a standard health questionnaire (PAR-Q). The subjects were randomly assigned to three groups: a traditional high-load resistance group (HL), a low-load group (LL) and a low-load partially occluded group (LLO). One subject from each group was removed from the study during the course of data collection. One subject missed the two final training sessions due to illness while two others were removed due to a researcher error in post-testing that resulted in incorrect collection of posttest power measures during the Wingate Test.

Wingate Testing

All subjects were tested during the first two sessions and again on the last session of the training period using a Wingate test for power on a *Monark Cycle Ergometer*. All subjects were confined to the same equipment during all training sessions and were instructed to remain seated during testing. A test resistance was determined using a standard Wingate protocol of $75 g \cdot kg^{-1}$ for each subject (MacIntosh et al., 2003). Revolutions per minute and power were averaged every 5s by a computer program interfaced to the cycle ergometer, and all readings are reported. Peak-Power was determined and reported as the initial 5s average for Watts during the test.

An initial Wingate Test was conducted in the first pre-test session to allow subjects to acclimate to the procedure. During a second pre-test session, subjects performed a second Wingate Test, and the results from this test are reported for as each subject's pre-test Peak-Power output, Watts/kilogram and Average Power. Subjects were weighed prior to each pre-test data Wingate session and their weight for the second pretest was reported and used during all calculatioins, including post-test calculations to demonstrate actual improvement relative to the initial Wingate and training resistances utilized. During the final session of training, post-testing was conducted using a final Wingate Test and these data were reported as each subject's post Peak-Power, Relative Peak-Power (Watts/kilogram) and Average Power for the 30 second test.

Vertical Jump Testing

A standard counter movement vertical jump test was utilized during pre-testing and post-testing as a secondary means to monitor changes in anaerobic power. Subjects performed three counter movement jumps, jumping as high as they could. The difference between stand-and-reach height and height jumped is reported as Vertical Jump (VJ). Three trials were conducted with 1-minute allowed for rest between the jumps. The best jump was reported as each subject's VJ.

Pre-testing for the VJ Test was performed prior to Wingate testing and results are reported as Pre-Vertical Jump height. During post-testing, the VJ Test was conducted prior to Wingate testing, and results are reported as Post-Vertical Jump height.

Instrumentation and Pressure Selection

Blood pressure cuffs made by Hokanson Medical Supplies Inc. (dimensions 6x83cm) were attached to the proximal end of the thigh, just below the acetabulofemoral joint for subjects in the LLO group, and inflated to 150mmHg as indicated by Sumide et al. (2009) (Figure 5). The researcher attached the cuffs after the completion of a 5-minute warm-up at a self-selected pace on the cycle ergometer. The pressure selected was lower than pressures used in standard blood pressure measuring procedures and according to all available research has caused no ill effects in combination with resistance exercise (Sumide et al., 2009; Cook et al., 2007). For all training session, the cuffs remained inflated from just prior to the first interval, until the completion of the last interval (Cook et al., 2007). The researcher monitored pressure through the use of a sphygmomanometer and maintained this pressure throughout the training session accordingly.

Training sessions

The HL group trained at a resistance (R) set to intensity (I) of 95% of the subject's peak power, as determined from maximum peak-power achieved during the Pretest Wingate Trial (PP_w). The average RPMs, reported during the first 5s interval of the pretest, were accepted as the subject's maximum cadence and were used to calculate training resistances with the following equation:

$$R = I \times PP_w / (\text{rpms} \times 1.2)$$

The resistance was not altered during any training session from the value determined during pretesting. The low-load groups (LL and LLO) trained at a resistance set to 45% of the determined peak power from the pretest Wingate trial. This was determined in the same manner as the HL group's resistance. During training sessions, subjects within the

LLO group performed all exercises with blood pressure cuffs attached to the proximal end of the thigh, just distal to the hip joint, as noted. No subject was allowed to participate in a training session without two days recovery from the prior session. Each training session began with a 5 min warm-up, and upon completion the cycle ergometer resistance was adjusted for each individual. At this point cuffs were attached to subjects in the LLO group and inflated to the stated pressure. Subjects were then provided the session's workout (for a complete training schedule see Appendix F). Subjects were instructed to pedal as fast as possible during each interval. The researcher provided instructions to the subjects as when to begin and when to stop pedaling for each interval until the completion of the session. The cuffs remained inflated on the LLO subjects throughout all training sessions until the completion of the last interval. Differences between the groups within each session are the selected load (or resistance) and whether subjects were exercising under conditions of occluded flow or free-flow.

Analysis

SPSS version 17.1 was used to run all data analyses. Group means for Weight, Pre- and Post-Vertical Jump, RPMs, and Group Mean Total Work Produced were all calculated. Groups' means and standard deviations for Peak-Power, Average Power (power output average for the 30-second Wingate tests), and Relative Power (average Watts/kilogram) are reported all reported. A 3x2 mixed measures ANOVA was used to analyze group interactions and is reported at a level of $p < .05$. A further analysis using 2x2 repeated measures ANOVAs were utilized to investigate group to group differences for Relative Peak-Power (Watts/kilogram), Absolute Peak-Power (Watts), Average Peak-Power (Watts) and Vertical Jump (inches).

Figure 1. Cuff attachment location

CHAPTER 4
RESULTS AND DISCUSSION

The purpose of this study was to determine the efficacy in utilizing a blood pressure cuff to occlude active musculature during sprint-training bouts on a cycle ergometer with the overall aim of increasing peak power output. Beyond the specific training loads selected for each group and the conditions of partial occlusion for the LLO group, all other training conditions were the same between the groups. For a full schedule of training sessions see Appendix F.

Results

No significant differences were found between the groups during pretesting within any of the tested variables. Group means for Weight (lb.), Training Resistance (kg), Pre- and Post-Vertical Jump (in) and Group Mean Total Work Produced (W) after completing all training sessions are reported in Table 1. Group means and standard deviations for all pre and posttest Wingate power measurements are reported in Table 2. Initial testing using a 3x2 mixed ANOVA showed not significant group interaction, although significance was approached, F (1, 18) = 3.175, p = .063, η^2 = .261.

Upon further statistical analysis utilizing follow up ANOVAs, the LLO and HL groups improved significantly for Relative Peak-Power (W/kg) from pre- to post testing, $p < .05$. This is demonstrated in Figure 2, which shows the LLO and HL groups' significant improvements for Relative Peak-Power (W/kg) from pre- to post-testing (14.4% and 14.1%, respectively), while the LL group shows no significant increase

(4.6%). There was no statistical improvement in Absolute Peak Power, Average Power, or Vertical Jump within any group (Figures 3 and 4). Although significance could not be reported, Figures 3 and 4 illustrate that Absolute Peak Power and Average Power had strong trends for improvement in both the HL and LLO groups.

Table 1. Group Means for Weight, Training Resistance, Pre- & Post-Vertical, and Total Work Produced

Group	N	Weight (lb.)	Training Resistance (kg)	Pre Vertical (in)	Post Vertical (In)	Total Work Produced (W)	
LLO	7	149	2.3	18	19	8,203.9	± 1248.2
HL	7	179	6.1	19	20	19,664.4	± 3571.3 †
LL	7	188	2.9	21	21	10,251.8	± 1123.9

† Average Total Work Produced for the High-Load Group was significantly different from both LLO and LL Groups, p <.05. Reported with a CI of 95%.

Table 2. Mean Scores and Standard Deviations for Wingate Power Measurements

Group	Pre PeakPower (W)		Post PeakPower (W)		Pre Peak Watts/kg		Post Peak Watts/kg		Pre 30sec Avg Power (W)		Post 30sec Avg Power (W)	
LLO	841.7	±186	960.1	±196	12.5	±1.2	14.3	±1.3†*	439.7	±114	512.2	±138
HL	1005.0	±282	1140.6	±248	12.3	±2.5	14.1	±2.1†	548.0	±143	612.1	±148
LL	1105.6	±184	1150.6	±194	13.0	±1.2	13.6	±2.0	589.3	±101	624.8	±96

† Significance was found within the LLO and HL Groups for Peak W/kg from pre- to post testing, p < .05.

* The LLO Group's improvement in W/kg after training was significantly greater than the LL Group, p < .05.

The LLO group improved significantly in Relative Peak-Power (W/kg) when compared to the LL group, F (1,12) = 5.226, p = .041, η^2 =.303 and the HL group's improvement for Relative Peak-Power (W/kg) approach significance when compared to the LL group, F (1,12) = 3.603, p = .082, η^2 = .231. No other significant group interactions can be reported: Absolute Peak Power (W), F (1, 18) = 2.682, p= .096, η^2 = .230, Average Power, F (1, 18) = 2.403, p= .119, η^2 = .211, and Vertical Jump, F (1, 18) = .210, p = .813, η^2 = .023. No significance was found within the LL group from pre- to post testing for any repeated measure. Pre- and posttest data for all individuals is reported within Appendix C, while individual workout data is reported in Appendix E.

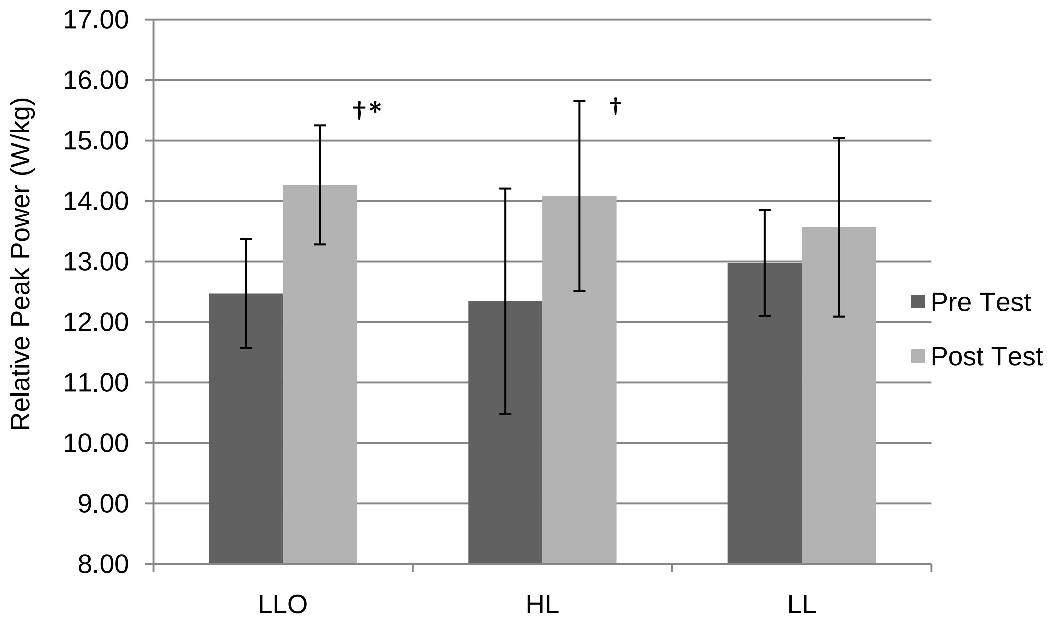

Figure 2. Group Means for Relative PeakPower (Watts/kilogram). Reported at a 95% Confidence Interval. LLO = Occluded Group, HL = High Load Group, LL = Low-Load Group. † Significantly different within the group from pre to post testing, $p < .05$. * Significantly different from LL posttest, $p < .05$.

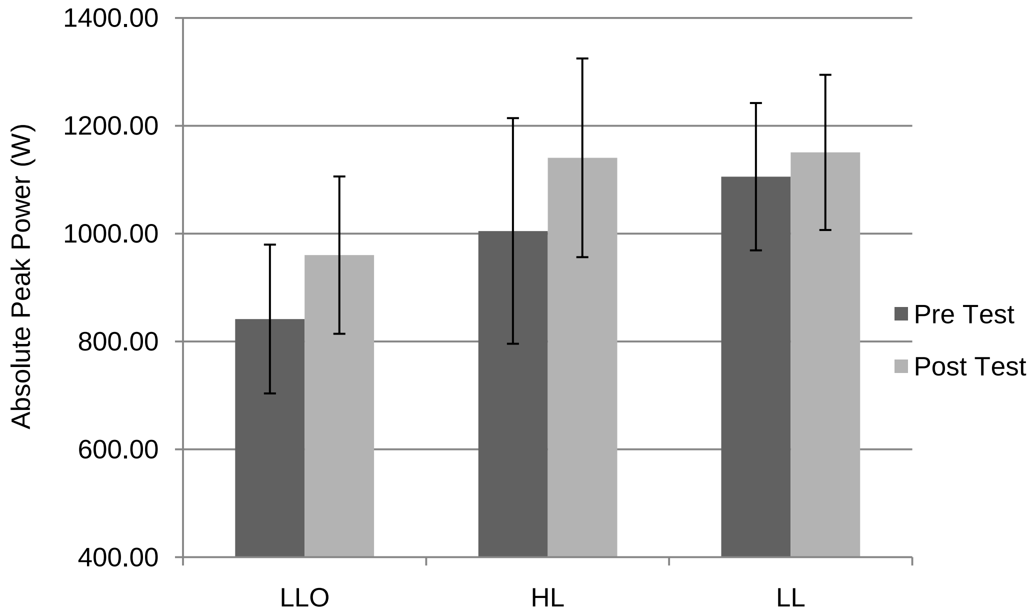

Figure 3. Means for pre and posttest Absolute Peak Power recorded during the first 5-second interval of a Wingate Test (W). Reported at a 95% Confidence Interval. LLO = Occluded Group, HL = High Load Group, LL = Low-Load Group.

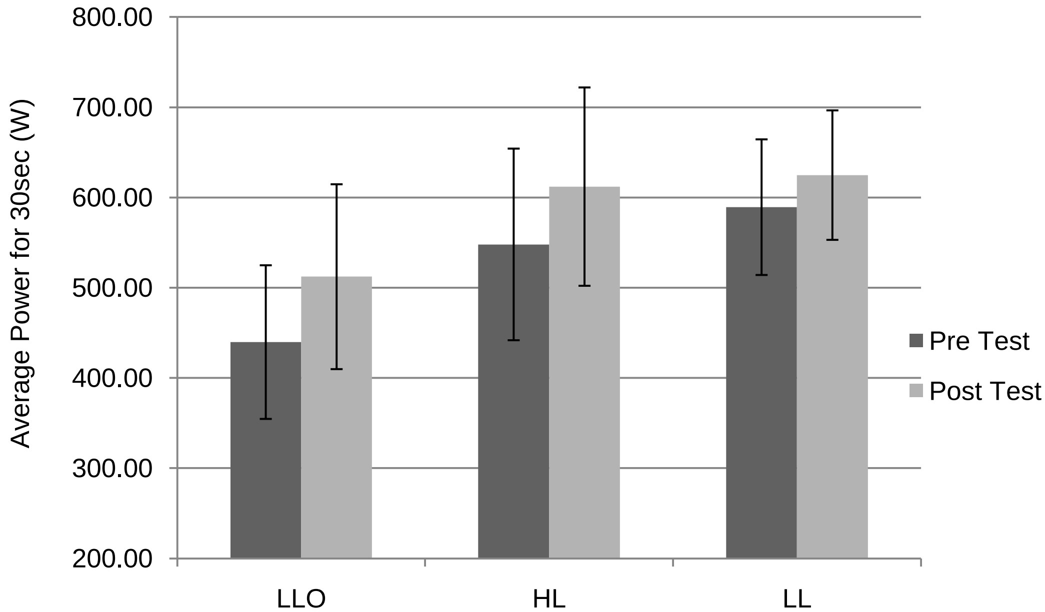

Figure 4. Group Means for Average Power During pre and posttest 30-second Wingate Trials (W), reported at a 95% CI. LLO = Occluded Group, HL = High Load Group, LL = Low-Load Group.

Discussion

After training under occluded conditions during all-out sprint efforts on a cycle ergometer, the Low-Load Occluded group saw a 14.4% increase over the Low-Load group's 4.6% increase in Relative Peak Power output. This was accomplished even though both groups were training at the same relative resistance set to 45% of Wingate Testing flywheel resistance (3.375% of subject bodyweight). The improvement in the Occluded group was statistically equal to the High-Load group's improvement (14.4% to 14.1%). This was despite the HL group training at over double the flywheel resistance set to 95% of Wingate Testing resistance (7.125% of subject bodyweight), which is more than double the Occluded group's flywheel resistance. This difference in resistance resulted in the HL group producing double the overall work output during training compared to the Occluded group, illustrated in Figure 4. This work output was calculated based on the assumption that all subjects performed all training sets at a maximum cadence.

Subjects who trained with partially occluded musculature and low loads demonstrated gains in Relative Peak Power output equal to subjects pedaling at double the resistance without occluded conditions. This is a unique finding because it illustrates that utilizing cuff training allows for less than half the overall training load typically necessary to produce significant results. Partial vascular occlusion appears to cause a specific stimulus capable of supplementing high resistance, which is supported by the Low-Load group's failure to improve significantly, even though their workload was equal to the Occluded group's. These results illustrate a clear training effect taking place due to the specific stimulus of partial occlusion applied during sprint pedaling.

This is supported by more recent studies which consistently show that performing resistance training with partial vascular occlusion and low loads results in large gains in strength, muscular size and muscle fiber activation (Takarada et al., 2001; Takarada et al., 2004; Sumide et al., 2007; Leonneke & Pujol, 2009). Yet, these studies differed from this current study in that they all examined training protocols which isolated muscles groups of a single joint and trained for, and measured signals of hypertrophy. This present study however, examined whether partial vascular occlusion would be effective when paired with training aimed at increasing maximal power output during a task that involved a large amount of muscle mass across multiple muscle groups.

The exact cause for this improvement in the LLO group is unclear. What is certain is the overall volume of work produced during training was less than half the volume of the HL group (Figure 5). Also, the amount of time under occluded conditions for each training session was under 10 minutes for every session. Although not measured, it is unlikely that there was a significant increase in muscle size or maximal strength following training, as the training intervention was relatively short, being less than 30-minutes per week for all groups. It is well established that higher training volumes are necessary to greatly increase muscle size (Sale, 1992; Baechle & Earle, 2008). Due to these factors, the improvements are likely not due to the commonly measured signals associated with hypertrophy, that were measured in previous studies examining vascular occlusion during resistance training. It is more likely that this training enhanced the functioning of the neuro-muscular system.

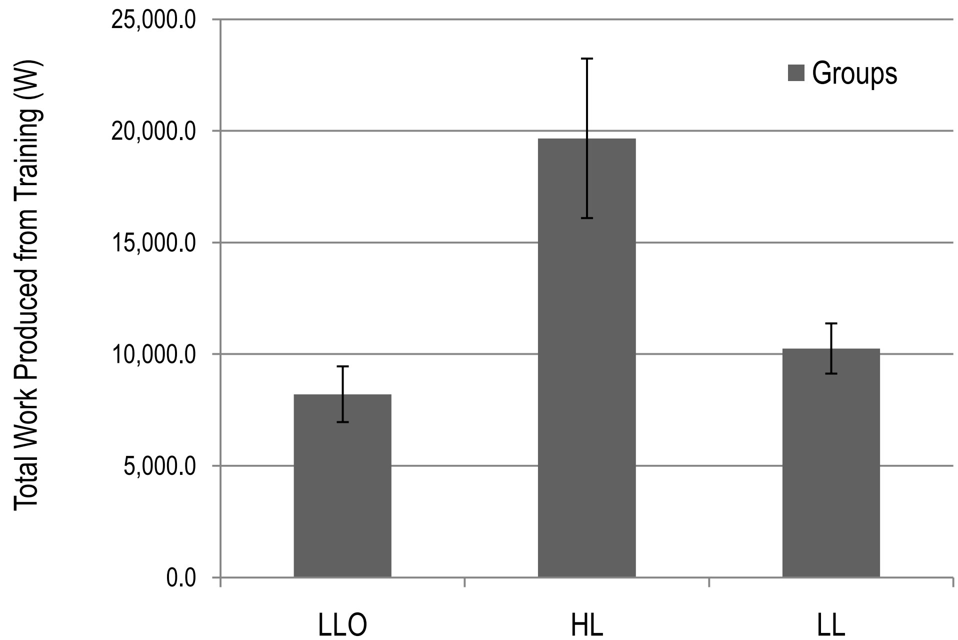

Figure 5. Group Mean Total Work Produced From Training on a Cycle Ergometer (reported in watts at a 95% CI). Determined by calculating the average watts produced by each group per training session and then summing these averages.

To better understand how the LLO group improved significantly, it may be easier to first understand how the HL group improved in Relative Peak Power. It is understood that training at intensities near maximum-resistances requires the reorganization of the nervous system to allow the recruitment of high-threshold, high-energy motor units. As a result of a larger percentage of the muscle being active, there is an abrupt decrease in free ATP and PCr stores. This places a large amount of stress on the neuromuscular system and time to fatigue is rapidly decreased, yet this high-load/low-repetition training translates directly to increases in maximum force and power (Baechle & Earle, 2008). The HL subjects were under great stress during the maximal short sprint repeats on the cycle ergometer. Over the course of the 10 training sessions, their neuromuscular coordination and their ability to quickly overcome the high resistances for the specific task likely increased. Since high-load training can also increase the firing rate of the involved motor units, greater force production was seen during post testing (Sale, 1992).

Improvements of up to 25% in maximal force can occur quickly with the introduction of a new training stimulus (four to six weeks) as a result of neural adaptations from resistance training (Baechle & Earle, 2008). As noted, this is the result of faster firing-rates and an improved ability to recruit high threshold motor units (MU) within the agonist musculature (Sale, 1992). It is also the result of improved coordination, or motor learning, within the nervous system (Moritani, Oddsson, & Thorstensson, 1990). This is supported by evidence that the CNS preferentially recruits specific motor units to improve the application of force (Grimby & Hannerz, 1976).

Thus, improved coordination of the involved muscles, faster and stronger contractions, or faster activation of high-threshold motor units by the central nervous system, are all likely to have occurred within the HL group.

Sale (1992) noted high-velocity movement patterns increase high-velocity performance. Training examples of this are found in power lifting and plyometric strength training (Chu, 1996). Based upon this evidence, it appears the nervous system can learn to immediately activate fast-motor units over lower-force producing units. This is possible through high velocity training regardless of the level of resistance, so long as it remains task specific (Sale, 1992; Duchateau, Le Bozec, & Hainaut, 1986; Moritani et al., 1990).

Understanding this concept, paired with the known signals of increased anaerobic glycolysis during bouts of decreased PO_2, the gains of the LLO group begin to be explained. Exposure to hypoxic conditions in active musculature results in marked increases in La+ and ADP and inorganic Phosphate, with increased fluid buildup in the local tissues. As subjects are exposed to partial vascular occlusion during intervals of high speed low-resistance activities, ATP and PCr stores are depleted quickly and fail to replenish during resting intervals due to a lack of O_2 (Lanza, et al, 2005).

As the LLO group subjects underwent multiple sprints during each training session, their ability to recover was significantly hindered by the restriction of blood flow from the active musculature. It is known that the Alactic energy sources are prevented from fully recovering and therefore contributing extensively to each successive interval, until the restoration of blood flow and PO_2 (Cook et al., 2007). A decrease in resting ATP and PCr stores results in a lowered capacity to generate high forces at high speed. Even though the subjects in the LLO group worked with resistances equaling half those used by the HL group, when placed under conditions of partial occlusion their overall capacity to generate force was likely decreased through the decreased involvement of the Alactic and oxidative systems in supplying and replenishing ATP. Increased contributions from anaerobic glycolysis and a greater activation of higher threshold motor units were required to support the activity, in spite of the relatively low-load. The LLO was likely able to train as effectively as the HL group in terms of activating higher threshold motor units, typically only accessed during training at high resistances (Moritani et al., 1992; Wernbom et al., 2009). This resulted in a number of previously mentioned possible neuromuscular adaptations contributing to the success of this stimulus.

While more research into this training modality and programming is necessary, cuff training as a means to specifically increase power production based on these results, has merit. Further, this is clear evidence that this training is as effective as high resistance training but at half the work load. This lower overall work load puts less physical stress on the active muscles and the body, possibly causing less structural damage and reducing recovery time between training bouts. This requires further research, specifically into the acute and long term effects of traditional power training compared to low load cuff training on instances of muscle stress and recovery. Vascular occlusion training is associated with lower instances of DOMS when compared to traditional resistance training (Wernbom et al., 2009), and this may be transferrable to the type of training examined in this study. If it holds true, then this training has potential to allow for more quality training sessions.

Also, after examining the results for VJ, it appears that sprint training on a cycle ergometer has no effect on counter movement jumping ability. But this does illustrate that cuff training seems to adhere to the principle of specificity, furthering the hypothesis that any improvements to PP were the result of improved neuro-muscular functions. Like most any training activity, the programming methods dictate the program outcomes. This study clearly illustrates that partial vascular occlusion can cause significant improvement in the specific movement pattern trained throughout the experiment, in this case high speed pedaling. It is not unexpected that improved power output during pedaling did not translate to improved vertical jumping ability, but it would appear valid to test this efficacy of partial vascular occlusion combined with high velocity plyometric training or power lifting.

Chapter 5

Summary, Conclusions, Implications And Recommendations

The purpose of this study was to expand the boundaries of cuff training by examining how effective it is at improving power output in a high speed, multi-joint task. Peak-power (PP), Relative Peak Power (W/kg) and Vertical Jump (VJ) were measured before and after a 12-session training cycle for three groups: Low-Load Occluded (LLO), Low-Load Free-Flow (LL) and High-Load Free-Flow (HL). The LLO group trained with blood-pressure cuffs attached to the proximal end of the thigh, which were inflated to 150 mmHg. Pre and Post testing for power measurements were conducted through the use of a 30-second Wingate test. It was hypothesized 1) that the LLO and HL groups would both improve significantly from pre to post testing for all measures, and 2) both would be significantly improved when compared to the LL group for Relative Peak-Power (W/kg) and Vertical Jump (VJ).

Each group followed the same training schedule, but the LL and LLO group trained at 45% of their Wingate resistance, while the HL group trained 95% of their Wingate resistance. Statistical analysis revealed that this training program was able to produce significant improvements for Relative Peak-Power (W/kg) for LLO and HL groups but not for the LL group, $p < .05$. Further analysis revealed that the LLO group improved significantly over the LL group from pre to post testing ($p = .041$) and the HL group's improvement neared a significantly greater improvement compared the LL group (*p* = .082). No other measures produced significance from pre to post testing, although PP and Average Power neared significance for both the LLO and HL groups.

Conclusions

This study demonstrates that combining partial vascular occlusion with low loads during a complex high-speed task such as sprinting on a cycle ergometer can improve peak power as effectively as traditional sprint training with high resistances, which mimic the resistance of the test condition. It is also clearly shown that the use of a partial vascular occlusion provides a unique stimulus to provoke adaptation. The significantly greater improvement of the LLO group over the LL group demonstrates this, as both groups followed the same training program, except for the addition of occluded conditions for LLO subjects.

Implications and Recommendations

The results of this study illustrate that cuff-training goes beyond the findings of previous studies, which have shown that cuff training works to improve fiber cross-sectional area, muscle buffering abilities and maximal force production in single joint concentric contractions. It also works to produce significant improvements in peak power output during a high-speed movement involving multiple joints.

The less overall work (W) produced in training indicates that cuff training may reduce recovery time. If true, then it is a reasonable to predict that with low-load cuff-training, subjects would undertake a greater number of quality training sessions within the same micro- or macro-cycle, which theoretically would result in greater gains to strength or power. This faster recovery time after exposure to a training session is a similar trait of Anabolics, which is one of the major advantages a steroid offers to the athlete. Cuff training may offer a unique advantage here through both rapid increases in muscle size and recovery found when using a steroid, but without the ethical, financial and legal ramifications. While more research and clinical application is clearly necessary, it would appear logical to draw this conclusion, making these investigations worthwhile to researchers. Also, like most any training activity, the programming methods dictate the program outcomes. While no significant findings were discovered for vertical jumping ability, this study did clearly show significant improvement in the specific movement pattern trained throughout the experiment: high speed pedaling. It is not unexpected that improved power output during pedaling did not translate to improved vertical jumping ability. Yet, because cuff training seems to adhere to the principle of specificity, it would be interesting to examine vertical jump performance after jump training under conditions of restricted flow. The challenges in such an experiment would lie in measuring the activity's intensity, and also overcoming the limitations to movement and comfort caused by the cuff design. Currently the cuffs used are not made for rapid movements in a 3D plane and are cumbersome to subjects due to the tubing and pressure monitoring equipment. Elastic bands or tourniquets can be used, but present no means of measuring the amount of pressure they elicit.

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APPENDIX A.
PATIENT INFORMATION FORM

Chris Popovici, an Exercise Science Graduate Assistant at SUNY Cortland, is preparing to conduct a study for research towards his thesis. The study will require volunteers to participate in a 6 week, 12 session training program. The training will take place on a cycle ergometer and sessions will last for approximately 10 minutes. As part of pre and post testing sessions, subjects will be asked to complete Wingate tests, each 30 seconds in length, on the cycle ergometers, and a vertical jump test, as a means to measure the results of the training on power development. Volunteers will be selected at random and assigned to one of three training groups: A traditional high resistance sprint training group, a low resistance group, or a group exercising under conditions of partial vascular occlusion with low-resistances. The risks involved with this study do not exceed those encountered in daily exercise programs. Individuals selected for the study will be provided an information sheet containing details about the training sessions and informed consent will be provided prior to beginning the study.

For students selected from Mr. Popovici's Physiology labs, extra credit for their time and participation will be offered. For those students from these lab sections not selected who still wish to pursue extra credit, a paper assignment will offered in its place. Further details can be provided during the lab sessions.

Participation in this study is voluntary and if an individual decides to withdraw from the study at any point in time, there will be no penalty for doing so. If you are interested in being involved with this study please return this form to Chris Popovici's faculty mailbox in the Kinesiology department office or to his office in Van Hoesen C-119E. As we are selecting participants at random, not everyone will be selected to participate. You will be notified if you are selected to participate in this study, and arrangements for the first session will be made.

Students Name: ______________________________ Age: _______________

Email: _____________________________
May we contact you via this Email? (Yes) (No)

Phone: ______________________
May we contact you using this number? (Yes) (No)

Schedule: Block out or X out the times when you are **NOT** available

Times:	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
9am							
10am							
11am							
Noon							
1pm							
2pm							
3pm							
4pm							
5pm							

APPENDIX B.

State University of New York College at Cortland
<u>Informed Consent</u>

You have been invited to participate in a research project conducted by graduate student Christopher Popovici of the Kinesiology Department at SUNY Cortland. The researcher requests your informed consent to be a participant in the project described below. The purpose of the project is to determine the effectiveness of using low resistance exercise under conditions of partially restricted blood flow to working muscles in attempt to improve power output. Please feel free to ask about the project, its procedures, or objectives.

If you agree to participate, you will be asked to attend 12 training sessions over a 6-week span. Each session will contain 6-8 short sprints on a stationary bicycle called a cycle ergometer for 4-8 seconds in length. Some participants may be asked to perform these sessions with blood pressure cuffs attached to their upper thigh and inflated to a low pressure similar to that used when a doctor takes a patient's blood pressure reading. The lead researcher will assist you in the placement of these cuffs. All subjects will also be asked to perform a standing vertical jump test and a Wingate test for power on cycle ergometer at the beginning of the study and at the end to measure the effectiveness of the training protocol. The opportunity to participate in this study will be made available to approximately 24 students from several classes at SUNY Cortland.

The risks associated with your participation in this study are minimal as they are similar to those associated with light exercise. Only the researcher will have access to your results and these will be stored on a flash drive. This flash drive and all other data will be stored in a locked cabinet in the lead researcher's office for no more than 2 years, upon which all files will be deleted. At no time will your name be associated with the data or results. Only group aggregate scores will be reported.

You are free to withdraw consent at any time without penalty. Additionally, at any time, you may ask the researcher to destroy any other data or information collected.

If you have any questions concerning the purpose or results of this study, you may contact Chris Popovici at (585) 329-2619 or at christopher.popovic@cortland.edu. Other contacts include: Dr. James Hokanson, Professor of Kinesiology at (607) 753-4964 or james.hokanson@cortland.edu. For questions about research at SUNY Cortland or questions/concerns about participant rights and welfare, you may contact Amy Henderson-Harr, IRB Administrator, and IRB Administrator, PO Box 2000, Cortland, NY, 13045 (phone (607) 753-2511 or email irb@cortland.edu). In the event of an injury please contact the SUNY Cortland Health Center in room B-26 of Van Hoesen Hall at (607) 753-4811.

I (print name) **___________________________________ have read the description of the project for which this consent is requested, understand my rights, and I hereby consent to participate in this study.**

Signature: __________________________________ Date: _________________

APPENDIX C.
SUBJECT TO SUBJECT DATA ORGANIZED BY GROUP

Pre and Post Test Data for LLO Group

Subject	Groups	Body Weight	Wingate Resistance	PeakPower	RPMs	AvgPower	Watts/kg	Vertical Jump
		Pre Test						
1	LLO	74.66 kg	5.6 kg	1083.00 W	161	554.00 W	14.51 W/kg	23 in
2	LLO	63.35 kg	4.8 kg	821.00 W	144	420.00 W	12.96 W/kg	19 in
3	LLO	53.39 kg	4.0 kg	616.00 W	128	293.00 W	11.54 W/kg	13 in
4	LLO	52.94 kg	4.0 kg	616.00 W	129	293.00 W	11.64 W/kg	18 in
5	LLO	65.61 kg	4.9 kg	780.00 W	132	432.00 W	11.89 W/kg	20 in
6	LLO	74.66 kg	5.6 kg	1008.00 W	150	517.00 W	13.50 W/kg	18 in
7	LLO	85.97 kg	6.4 kg	968.00 W	125	569.00 W	11.26 W/kg	18 in
Averages:				841.71 W	139	439.71 W	12.47 W/kg	18 in
		Post Test						
1	LLO	74.66 kg	5.6 kg	1240.00 W	185	650.55 W	16.61 W/kg	24 in
2	LLO	63.35 kg	4.8 kg	901.00 W	158	493.36 W	14.22 W/kg	19 in
3	LLO	53.39 kg	4.0 kg	674.00 W	140	315.37 W	12.62 W/kg	14 in
4	LLO	52.94 kg	4.0 kg	794.00 W	167	360.80 W	15.00 W/kg	19 in
5	LLO	65.61 kg	4.9 kg	914.00 W	155	507.66 W	13.93 W/kg	20 in
6	LLO	74.66 kg	5.6 kg	1083.00 W	161	572.79 W	14.51 W/kg	19 in
7	LLO	85.97 kg	6.4 kg	1115.00 W	144	685.06 W	12.97 W/kg	19 in
Averages:				960.14 W	159	512.23 W	14.27 W/kg	19 in

Pre and Post Test Data for HL Group

Subject	Groups	Body Weight	Wingate Resistance	PeakPower	RPMs	AvgPower	Watts/kg	Vertical Jump
	Pre Test							
8	HL	67.87 kg	5.6 kg	940.00 W	154	465.00 W	13.85 W/kg	19 in
9	HL	90.5 kg	4.8 kg	1428.00 W	175	667.00 W	15.78 W/kg	21 in
10	HL	92.76 kg	4.0 kg	1281.00 W	153	731.00 W	13.81 W/kg	20 in
11	HL	79.19 kg	4.0 kg	1048.00 W	147	589.00 W	13.23 W/kg	23 in
12	HL	92.76 kg	4.9 kg	867.00 W	104	546.00 W	9.35 W/kg	20 in
13	HL	63.35 kg	5.6 kg	573.00 W	101	289.00 W	9.05 W/kg	11 in
14	HL	79.19 kg	6.4 kg	898.00 W	126	549.00 W	11.34 W/kg	22 in
Averages:				1005.00 W	137	548.00 W	12.34 W/kg	19 in
	Post Test							
8	HL	67.87 kg	5.6 kg	1086.00 W	178	569.04 W	16.00 W/kg	19 in
9	HL	90.5 kg	4.8 kg	1381.00 W	170	738.65 W	15.26 W/kg	21 in
10	HL	92.76 kg	4.0 kg	1460.00 W	175	809.53 W	15.74 W/kg	20 in
11	HL	79.19 kg	4.0 kg	1205.00 W	169	579.06 W	15.22 W/kg	24 in
12	HL	92.76 kg	4.9 kg	1027.00 W	123	588.62 W	11.07 W/kg	19 in
13	HL	63.35 kg	5.6 kg	704.00 W	123	344.33 W	11.11 W/kg	13 in
14	HL	79.19 kg	6.4 kg	1121.00 W	157	655.19 W	14.16 W/kg	22 in
Averages:				1140.57 W	156	612.06 W	14.08 W/kg	20 in

APPENDIX D.
SUBJECT TO SUBJECT DATA ORGANIZED BY GROUP (CONT.)

Pre and Post Testing for LL Group

Subject	Groups	Body Weight	Wingate Resistance	PeakPower	RPMs	AvgPower	Watts/kg	Vertical Jump
	Pre Test							
15	LL	95.02 kg	7.1 kg	1295.00 W	151	582.00 W	13.63 W/kg	21 in
16	LL	83.71 kg	6.3 kg	1182.00 W	157	689.00 W	14.12 W/kg	20 in
17	LL	74.66 kg	5.6 kg	1008.00 W	150	499.00 W	13.50 W/kg	24 in
18	LL	106.33 kg	8.0 kg	1328.00 W	139	694.00 W	12.49 W/kg	19 in
19	LL	82.35 kg	6.2 kg	933.00 W	126	623.00 W	11.33 W/kg	22 in
20	LL	72.4 kg	5.4 kg	839.00 W	129	415.00 W	11.59 W/kg	15 in
21	LL	81.45 kg	6.1 kg	1154.00 W	157	623.00 W	14.17 W/kg	23 in
Averages:				1105.57 W	144	589.29 W	12.97 W/kg	21 in
	Post Test							
15	LL	95.02 kg	7.1 kg	1208.00 W	141	654.90 W	12.71 W/kg	22 in
16	LL	83.71 kg	6.3 kg	1350.00 W	179	695.39 W	16.13 W/kg	18 in
17	LL	74.66 kg	5.6 kg	1161.00 W	173	561.13 W	15.55 W/kg	26 in
18	LL	106.33 kg	8.0 kg	1328.00 W	139	709.12 W	12.49 W/kg	20 in
19	LL	82.35 kg	6.2 kg	933.00 W	126	682.66 W	11.33 W/kg	25 in
20	LL	72.4 kg	5.4 kg	839.00 W	129	435.65 W	11.59 W/kg	16 in
21	LL	81.45 kg	6.1 kg	1235.00 W	168	634.90 W	15.16 W/kg	21 in
Averages:				1150.57 W	151	624.82 W	13.57 W/kg	21 in

APPENDIX E.
EXAMPLE OF INDIVIDUAL WORKOUT DATA

Sample Workout Data: Workout #7

Subject	Group	Gender	Wght (kg)	Win. Res.	PP (w)	RPM	%Int	Kg Int	Sets	Total Work/ Set	Total W/ Session
1	LLO	M	74.66 kg	5.6 kg	1083.0 w	161.2	45.0%	2.5 kg	5	203.1 w	1015.3 w
2	LLO	M	63.35 kg	4.8 kg	821.0 w	144.0	45.0%	2.1 kg	5	153.9 w	769.7 w
3	LLO	M	76.92 kg	5.8 kg	1111.0 w	160.5	45.0%	2.6 kg	5	208.3 w	1041.6 w
4	LLO	F	52.94 kg	4.0 kg	616.0 w	129.3	45.0%	1.8 kg	5	115.5 w	577.5 w
5	LLO	M	65.61 kg	4.9 kg	780.0 w	132.1	45.0%	2.2 kg	5	146.3 w	731.3 w
6	LLO	M	74.66 kg	5.6 kg	1008.0 w	150.0	45.0%	2.5 kg	5	189.0 w	945.0 w
7	LLO	M	85.97 kg	6.4 kg	968.0 w	125.1	45.0%	2.9 kg	5	181.5 w	907.5 w
8	LLO	F	53.39 kg	4.0 kg	616.0 w	128.2	45.0%	1.8 kg	5	115.5 w	577.5 w
9	HL	M	67.87 kg	5.1 kg	940.0 w	153.9	95.0%	4.8 kg	5	372.1 w	1860.4 w
10	HL	M	90.5 kg	6.8 kg	1428.0 w	175.3	95.0%	6.4 kg	5	565.3 w	2826.3 w
11	HL	M	92.76 kg	7.0 kg	1281.0 w	153.4	95.0%	6.6 kg	5	507.1 w	2535.3 w
12	HL	M	79.19 kg	5.9 kg	1048.0 w	147.1	95.0%	5.6 kg	5	414.8 w	2074.2 w
13	HL	M	74.66 kg	5.6 kg	934.0 w	139.0	95.0%	5.3 kg	5	369.7 w	1848.5 w
14	HL	M	92.76 kg	7.0 kg	867.0 w	103.9	95.0%	6.6 kg	5	343.2 w	1715.9 w
15	HL	M	63.35 kg	4.8 kg	573.0 w	100.5	95.0%	4.5 kg	5	226.8 w	1134.1 w
16	HL	M	79.19 kg	5.9 kg	898.0 w	126.0	95.0%	5.6 kg	5	355.5 w	1777.3 w
17	LL	M	95.02 kg	7.1 kg	1295.0 w	151.4	45.0%	3.2 kg	5	242.8 w	1214.1 w
18	LL	M	83.71 kg	6.3 kg	1182.0 w	156.9	45.0%	2.8 kg	5	221.6 w	1108.1 w
19	LL	M	74.66 kg	5.6 kg	1008.0 w	150.0	45.0%	2.5 kg	5	189.0 w	945.0 w
20	LL	M	76.92 kg	5.8 kg	1021.0 w	147.5	45.0%	2.6 kg	5	191.4 w	957.2 w
21	LL	M	106.33 kg	8.0 kg	1328.0 w	138.8	45.0%	3.6 kg	5	249.0 w	1245.0 w
22	LL	M	82.35 kg	6.2 kg	933.0 w	125.9	45.0%	2.8 kg	5	174.9 w	874.7 w
23	LL	F	72.4 kg	5.4 kg	839.0 w	128.8	45.0%	2.4 kg	5	157.3 w	786.6 w
24	LL	M	81.45 kg	6.1 kg	1154.0 w	157.4	45.0%	2.7 kg	5	216.4 w	1081.9 w

APPENDIX F.
TRAINING SESSIONS SCHEDULE

Testing & Training Sessions

		HL Group		LLO Group		LL Group		
Week:	Session:	Int	Res	Int	Res	Int	Res	Rest
Week1	Introduction	Wingate 1		Wingate 1		Wingate 1		
	Pre-test	Wingate 2		Wingate 2		Wingate 2		NA
	Protocol 1	6x5s	95%	6x5s	45%	6x5s	45%	1 min
Week2	Protocol 2	2x2x4s	95%	2x2x4s	45%	2x2x4s	45%	1/3 min
	Protocol 3	4x8s	95%	4x8s	45%	4x8s	45%	2 min
Week3	Protocol 4	4x10s	95%	4x10s	45%	4x10s	45%	2 min
	Protocol 5	6x5s	95%	6x5s	45%	6x5s	45%	1 min
Week4	Protocol 6	2x2x4s	95%	2x2x4s	45%	2x2x4s	45%	1/3 min
	Protocol 7	5x4s	95%	5x4s	45%	5x4s	45%	2 min
Week5	Protocol 8	2x8-6-4s	95%	2x8-6-4s	45%	2x8-6-4s	45%	2 min
	Protocol 9	2x10s,2x4s	95%	2x10s, 2x4s	45%	2x10s, 2x4s	45%	3 min
			95%		45%		45%	2 min
Week6	Protocol 10	Rest		Rest		Rest		NA
	Post-test	Wingate 3		Wingate 3		Wingate 3		NA

APPENDIX G.

Physical Activity Readiness Questionnaire (PAR-Q)

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer YES or NO for each.

Y N Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Y N Do you feel pain in your chest when you do physical activity?

Y N In the past month, have you had chest pain when you were not doing physical activity?

Y N Do you lose your balance because of dizziness or do you ever lose consciousness?

Y N Do you have a bone or joint problem that could be made worse by a change in your physical activity?

Y N Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Y N Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more of these questions, talk to your doctor by phone or in person before you start becoming more physically active or before you have a fitness appraisal. Tell your doctor about the PAR-Q and the questions to which you answered YES.

If you answered NO to all PAR-Q questions, you can be reasonably sure that you can: start becoming more physically active – begin slowly and build up gradually.

I have read the above information or had it explained to me and understand that I am completely liable for any injury as well as my personal well-being while participating in this study.

____ _______________

Signature Date

APPENDIX H.

IRB Approval Documentation

MEMORANDUM

SUNY Cortland
Institutional Review Board

To:	Christopher Popovici James Hokanson, Kinesiology
From:	Jena Curtis, Primary Reviewer Institutional Review Board
Date:	10-26-2010
RE:	Institutional Review Board Approval

In accordance with SUNY Cortland's procedures for human research participant protections, the protocol referenced below has been approved for a period of one year:

Title of the study:	Low resistance exercise and lowered blood flow impact strength gain		
Level of review:	**Expedited**	**Protocol number:**	101114
Project start date:	Upon IRB approval	**Approval expiration date*:**	10-25-2011

* **Note:** *Please include the protocol expiration date to the bottom of your consent form and recruitment materials.* For more information about continuation policies and procedures, visit www.cortland.edu/irb/Applications/continuations.html

The federal Office for Research Protections (OHRP) emphasizes that investigators play a crucial role in protecting the rights and welfare of human subjects and are responsible for carrying out sound ethical research consistent with research plans approved by an IRB. Along with meeting the specific requirements of a particular research study, investigators are responsible for ongoing requirements in the conduct of approved research that include, in summary:

- obtaining and documenting informed consent from the participants and/or from a legally authorized representative prior to the individuals' participation in the research, unless these requirements have been waived by the IRB;
- obtaining prior approval from the IRB for any modifications of (or additions to) the previously approved research; this includes modifications to advertisements and other recruitment materials, changes to the informed consent or child assent, the study design and procedures, addition of research staff or student assistants, etc. (except those alterations necessary to eliminate apparent immediate hazards to subjects, which are then to be reported by email to irb@cortland.edu within three days);
- providing to the IRB prompt reports of any unanticipated problems involving risks to subjects or others;
- following the principles outlined in the Belmont Report, OHRP Policies and Procedures (Title 45, Part 46, Protection of Human Subjects), the SUNY Cortland College Handbook, and SUNY Cortland's IRB Policies and Procedures Manual;
- notifying the IRB of continued research under the approved protocol to keep the records active; and,
- maintaining records as required by the HHS regulations and NYS State law, for at least three years after completion of the study.

Miller Building, Room 402 • P.O. Box 2000 • Cortland, NY 13045-0900
Phone: (607) 753-2511 • Fax: (607) 753-5590

In the event that questions or concerns arise about research at SUNY Cortland, please contact the IRB by email irb@cortland.edu or by telephone at (607)753-2511. You may also contact a member of the IRB who possesses expertise in your discipline or methodology, visit http://www.cortland.edu/irb/members.html to obtain a current list of IRB members.

Sincerely,

Jena Curtis
IRB Primary Reviewer
School of Professional Studies