## Cardiff School of Sport

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### Dissertation title:
The effects of traditional strength and blood flow restriction training versus a combination of both on measures of strength, hypertrophy and power in elite athletes.

### Supervisor:
Dr Rhodri Lloyd

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(SCRAM)

Daniel A Ismail

St20000585
THE EFFECTS OF TRADITIONAL STRENGTH AND BLOOD FLOW RESTRICTION TRAINING VERSUS A COMBINATION OF BOTH ON MEASURES OF STRENGTH, HYPERTROPHY AND POWER IN ELITE ATHLETES.
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ACKNOWLEDGEMENT

First of all I would like to thank my tutor and supervisor Dr Rhodri Lloyd for his help and support. I have fully appreciated his knowledge and guidance throughout this entire process which has been invaluable. Secondly, I would like to thank Dr Jeremy Loenneke who inspired me to research the subject area. Furthermore, I would also like to thank the athletes who took a lot of time out of their very important commonwealth training schedule to participate in the study. Finally, I would like to thank Jamie Thomas and Nick Jones for providing assistance throughout the data collection process.
ABSTRACT

The purpose of this study was to investigate the effectiveness of varying training interventions and exposures, over a 7 week period on elite athletes. The effects of traditional strength training (TST, 80% of one repetition maximum [1RM], 4d/week), blood flow restriction (BFR, 30% 1RM, 2d/week), combined TST and BFR (TST-BFR, TST 4d/week and BFR 2d/week) were analysed on measures of hypertrophy, strength and power. Twenty seven elite athletes were randomly divided into the three training interventions (TST n=9, BFR n=8 and TST-BFR n=10) in a test, re-test experimental design. The increased thigh girth circumference and 1RM leg press strength in TST (1.6cm/2.6% and 20kg/6%), BFR (2.1cm/3.7% and 21.2kg/6.6%) and TST-BFR (3.2cm/5.1% and 39.9kg/11.7%) were all significant (p< 0.01) with a strong effect size for each group (η²s> .800). Countermovement jump did not change significantly (p> 0.05) in any of the aforementioned training interventions. The results suggest that BFRT could provide supplementary benefits to TST in improving muscular hypertrophy and strength when the two training modalities are combined in elite athletes. Furthermore, data presented in the study suggests that BFRT can provide athletes with quick time course adaptations in muscular hypertrophy and strength. Key words: muscle hypertrophy, muscle strength, power, sport performance, resistance exercise, strength training, ischemia, blood flow restriction, vascular occlusion, KAATSU, exertion, perception, elite athletes.
CHAPTER I

INTRODUCTION
CHAPTER 1

INTRODUCTION

The appropriate application of a given training stimulus can cause positive skeletal muscle adaptations (Schoenfeld, 2013). Central to the notion of physiological adaptation are principles which manipulate frequency, overload and progression (Karabulut et al., 2007). It is widely accepted that in order to elicit physiological adaptations the intensity exposure must be manipulated to dictate the nature of a said given adaptation (Raymond et al., 2013). A resulting factor in the dictation of exercise intensity causes adaptations of musculature hypertrophy, strength, power and has been regarded as the most influential factor in the prescription of training (de Salles, 2009). However, research analysing transient intramuscular ischemic methods, such as blood flow restriction (BFR) have used intensities between 20-50% of one repetition maximum (1RM) to elicit similar adaptations to high mechanical loading intensities which exceed 80% 1RM. A growing body of literature has supported the positive effects BFR has on physiological adaptations (Pope et al., 2013), skeletal morphology and function (Loenneke et al., 2012). The significantly low mechanical loading applied to BFR training (BFRT) challenges the notion of training intensity being the most influential factor in achieving physiological adaptations of musculature size and strength. Training intensities between 20-50% 1RM is seen as optimal during BFRT which is contrary to prescriptions of optimal dynamic strength training often being quantified as a function in excess of 80% 1RM (Wernbom et al., 2008).

The BFRT intervention has been in the literature since it was developed in the 1960's (Yamanaka et al., 2012). However, recently the training modality has been viewed as an alternative to conventional heavy resistance training methods for eliciting a similar strength and hypertrophic augmentation (Weatherholt et al., 2013). The BFR method restricts the most proximal area of the limb which under certain pressures encourages arterial blood flow to the exercising muscle, whilst occluding venous return invokes blood pooling (Fahs et al., 2012). A substantial amount of work has focused on the methodological applications of BFRT (Fahs et al., 2012; Loenneke et al., 2010; Loenneke et al., 2011a; Loenneke et al., 2013). Published studies have assessed intensity ranges between 20-50% 1RM (Abe et al., 2005; Cook et al., 2007; Wernbom et al., 2006), training frequencies ranging from two days a week to twice daily (Abe et al., 2005a; Abe et al., 2005b; Clark et al., 2011; Karabulut et al., 2011), restriction pressures ranging between 100-300 mmHg.
(Abe et al., 2005a; Fujita et al., 2007; Fry et al., 2010; Takarada et al. 2000b; Wernbom et al., 2006) and varying combinations of sets and repetitions (Abe et al., 2005a; Abe et al., 2005b; Cook et al., 2007; Clark et al., 2011; Karabulut et al., 2010; Wernbom et al., 2006). However, the optimal combination of treatment exposures is yet to be fully determined. To date, there is no optimal approach to train under BFR despite varying researchers suggesting guidelines (Fahs et al., 2012; Loenneke et al., 2011a; Loenneke et al., 2013). Research into BFR has applied the training modality to varying populations such as rehabilitating individuals, elderly, and untrained populations (Lejkowski et al., 2011; Patterson et al., 2011; Ishii et al., 2005). Despite BFR literature being under researched as a whole, research analysing elite populations training in combination with BFR is poorly understood. However, as developments into BFR research progress, comparisons have been conducted comparing BFRT to TST. The progression in research provided the scope of the present study. The scope was to investigate the impacts combining both training modalities would have on performance measures in an elite population. Therefore a test-re-test experimental design was applied to the present study where TST, BFRT and TST-BFR groups were tested on measures of muscle hypertrophy, strength and power.

The hypothesis of the present study was that all training interventions would have a significant effect on changes in muscle hypertrophy and strength. However, power determinants were only hypothesised to improve in the TST and TST-BFR groups. Furthermore, it was hypothesised that the combination of TST and BFR would be an effective training intervention elite athletes can implement into their training program. Additionally, it was hypothesised that BFRT would be an effective short term stimulus which elite athletes can utilise in order to achieve quick time course adaptations in muscular hypertrophy and strength.
CHAPTER II

LITERATURE REVIEW
Despite research providing evidence of increased mCSA between varying intensities of 1RM under BFR, it is unclear to what intensity elicits optimal increases in mCSA and strength. Studies assessing BFR in combination with varying intensities include body weight (Ishii et al., 2005; Yokokawa et al., 2008; Sumide et al., 2009), 20% 1RM (Takarada et al., 2004; Takano et al., 2005; Yasuda et al., 2005; Nakajima et al., 2011; Karabulut et al., 2011; Laurention et al., 2011; Yamanaka et al., 2012), 30% 1RM (Sata et al., 2005; Madarame et al., 2008; Yasuda et al., 2010; Yasuda et al., 2011a; Yasuda et al., 2011b) and 50% 1RM (Takarada et al., 2000; Takarada et al., 2002; Moore et al., 2004). Therefore, intensity would appear to be an integral training variable to consider when prescribing BFRT.

2.1 BFR mechanisms

Furthermore, when BFR is applied within a training intervention, there are many mechanisms which cause a variety of physiological responses. Blood pooling during BFR exposure causes a fluid shift induced through muscle cell swelling (Loenneke et al., 2012), whereas taking the occlusive stimulus off causes reactive hyperemia. Reactive hyperemia occurs as a consequence of Raynaud’s phenomenon (Bakst et al., 2008). The phenomenon transpires when there is a transient increase in blood flow following ischemia due to the lack of oxygen availability and the build up of metabolites (Cooke et al., 2005). Furthermore, ischemic reperfusion to the previously restricted muscle is caused following the removal of an occlusive stimulus (Horiuchi et al., 2012).

The cell swelling response is caused by vasodilation and restoration of blood flow which causes the pressure gradient needed to force the fluid shift from extracellular to intracellular space (Loenneke et al., 2012b). The reperfusion of blood flow has been suggested to stimulate positive effects on arterial compliance which is thought to be a result of arterial sheer stress (Patterson and Ferguson, 2010). This is an important for long term chronic adaptations, especially for athletes engaging in BFRT. Blood pooling and reactive hyperemia alters the nature of local hepatocytes to become more anabolic (Cermak et al., 2008). Muscle cell swelling has been postulated to cause the activation of mTORC1 and MAPK signalling pathways when exercise is combined with BFR.
(Thiebaud et al., 2014). Furthermore, the swelling of local hepatocytes induces the capability to inhibit catabolism; this would inherently alter the protein balance towards anabolism (Loenneke et al., 2012b).

Conversely, it has been postulated that cell swelling could be caused by inflammation or muscle damage (Yasuda et al., 2010). However, data has been generated to suggest that acute BFRT causes no change in muscle damage and oxidative stress markers (Abe et al., 2005 Abe et al., 2006; Fujita et al., 2008). Therefore, quick time course adaptations in musculature hypertrophy, following a period of BFRT is due to structural adaptations as opposed to a result of muscle cell swelling driven by inflammation or muscle trauma. Moreover, muscle cell swelling appears to be central to BFRT mediated adaptations which coalesce with varying physiological mechanisms to generate a greater hypertrophic potential following BFRT (Loenneke et al., 2012b).

Additionally, it has been documented that other factors influence this foundational mechanism other than muscle trauma and inflammation. Such factors include BFR causing hypoxic mediated conditions which augments an increased production of intracellular metabolites (Pope et al., 2013). Intracellular metabolites, however small in quantity, create an increased osmotic gradient which transiently influences muscle cell volume (Loenneke et al., 2012b). There is also data to support an increased stimulation of muscle protein synthesis (MPS) through the phosphorylation of downstream targets of the mechanistic target of rapamycin (mTOR) pathway (Fujita et al., 2007; Fry et al., 2010; Gundermann et al., 2012). A study conducted by Fujita et al. (2007) found that BFRT marked a threefold increase in phosphorylation of ribosomal protein S6 kinase beta-1 (S6K1) which is a regulator of translation initiation and elongation (Hackney et al., 2012).

The findings of Fujita et al. (2007) are supportive of the data provided by Fry et al. (2010) and Gundermann et al. (2012) because S6K1 is a downstream target of the mTORC1 pathway and therefore a net gain in protein synthesis would be evident once this pathway is stimulated. Conversely, BFR studies have shown that in terms of factors influencing protein degradation, such as mRNA transcripts (associated with proteolitic pathways) have been shown to be downregulated further than that of control groups exercising at 20% 1RM without BFR (Manini et al., 2011). Consequently, a reduction in catabolic mechanisms post exercise results in a net loss in the ratio between protein synthesis and degradation. Additionally, comparing heavy resistance exercise to BFRT, a study conducted by Kraemer et al. (1990) assessed the effects heavy resistance exercise would
have on plasma concentrations of GH and found a 100-fold increase. Conversely, Takarada et al. (2000a) also examined the same effect but after the investigation of a BFR intervention, the researchers found a 290-fold increase in plasma concentrations of GH. However, the extent of how influential these systemic hormones are, in regards to the anabolic response, is unclear (West et al., 2010). Additional mechanisms thought to be responsible for the physiological adaptations from BFRT are the proliferation of muscle cells as a consequence of reactive oxygen species (ROS) activation (Shimokawa., 2013). It has been shown that in hypoxic conditions there is an increase in xanthine oxidase activation occurring within the muscle (Korthius et al., 1985) which exposes reperfusion and signal transduction of muscle growth from the activation of ROS (Takarada et al., 2000a). Furthermore, studies such as Manini et al., (2011) and Laurentino et al., (2012) have found evidence to suggest that BFR suppresses messenger ribonucleic acid (mRNA) expression of genes which is supported by findings in a study conducted by Nielson et al., (2012) who also found evidence that myogenic stem cells were augmented when exercise was combined with BFR.

2.2 BFR and clinical populations

It is therefore clear why BFR and its positive adaptations have attracted a variety of populations. Conversely, the concept of applying an occlusive stimulus (i.e. knee wraps or pneumatic cuff) to restrict blood flow can be uncomfortable for a variety of populations such as individuals going through rehabilitation. However, those concerning themselves with rehabilitation and applying the training modality from a clinical standpoint have specifically exploited the effectiveness of BFRT due to the low load alternative (Lejkowski et al., 2011). Therefore, high intensity methods and the contraindications which expose rehabilitating patients are avoided (Wernbom et al., 2009). Research and varying case studies have examined patients after a variety of injuries such as anterior cruciate ligament reconstruction (Lejkowski et al., 2011; Ohta et al., 2003; Tarakeda et al. 2000) and osteochondral fractures (Loenneke et al., 2013). Data from the literature has provided evidence, specifically from a case study conducted by Loenneke et al. (2012) that BFR exposure can aid in the prevention of muscle atrophy.
Muscle atrophy and disuse atrophy is a common occurrence during post-surgical rehabilitation and the outcome often leads to the inability to fully recover and therefore increasing the risk of re-injury (Mendias et al., 2013). The case study by Loenneke et al. (2012) provided evidence that not only was muscle atrophy avoided but muscle mass was maintained with bone formation occurring just after 2d/week of 6 week leg BFRT. The evidence provided is by no means conclusive with only one subject being analysed during the case study. Furthermore, the formation and healing rate of bone documentation cannot be said to have occurred as a result of BFRT. However, researchers investigating the correlation between bone markers and BFRT have provided data to suggest there is a positive correlation after the training exposure (Beekley et al., 2005; Bemben et al., 2007; Karabulut et al., 2011). Nevertheless, a study conducted by Kim et al. (2012) provided evidence that high intensity training was more effective than BFRT in terms of eliciting a greater response in bone formation but as previously stated there are contraindications with this training modality and rehabilitation. However, similar findings are yet to be established within athletic populations. Moreover, combining BFR and rehabilitation has proven to be a beneficial supplement and is evident in the literature when applying the training exposure to elderly populations.

There is a substantial amount of research assessing BFR application towards the elderly population due to the population’s incapability of sustaining the necessary mechanical stress required to achieve muscular failure (Loenneke et al., 2011b). Studies which have used elderly populations combining BFR with walking include (Abe et al., 2006; Iida et al., 2011; Ozaki et al., 2011a; Ozaki et al., 2011b) and combining BFR with resistance training (Yokokawa et al., 2008; Patterson et al., 2011; Karabulut et al., 2010; Karabulut et al., 2011; Gualano et al., 2010). The data presented from the accumulated studies have provided evidence to suggest that BFR can positively influence hypertrophy and specifically strength adaptations within elderly participants. The studies range from samples of 1-44 men and women aged 64.5 ± 10.5, training under BFR between frequencies of 3 days a week over 4 weeks and 3 days a week over 12 weeks. Post training interventions strength increases improved by 17.4% ± 3%, training consisted of either 3 sets of 15 reps which was separated by 20s rest or 3 sets of 10 reps being separated by 30s rest. The data therefore concludes that BFR can be applied to this particular population over TST methods where elderly populations maybe prone to orthopaedic injuries (Pollock et al., 1991 and Roth et al., 2000). However, data increases
in the region of 17.4% in strength are unlikely to be found when analysing highly trained athletic individuals.

2.3 BFR and healthy untrained populations

Conversely, research analysing healthy individuals engaging in intensities as low as 20% 1RM in combination with BFRT have accumulated data in the region of 3.0-20.3% increases in muscle cross-sectional area (mCSA) (Ishii et al., 2005 and Takarada et al., 2000). The range in data signifies the lowest and highest significant changes of mCSA within the current literature. However, the method of training exposure is very contrasting between the studies and therefore is reflected in the results. The significance of such findings in terms of achieving the maximum potential of adaptations within a population means that 3% in mCSA would be of less significance to a novice/elderly/rehabilitating population in comparison to elite athletes who are already highly trained.

The training prescription administered by Ishii et al. (2005) recorded a 3% mCSA change in thigh hypertrophy. The method contained 6 exercises, 2 body weight compound leg exercises, squat and lunges within a circuit of 11 participants who trained 3/week over 8 weeks under BFR exposure. The BFR method, administered very low pressures (80-120 mmHg) resulting in venous return unlikely being occluded when compared to previous pressure which have used (160-240 mmHg) during BFR of the thigh (Yasuda et al., 2005; Takarada et al., 2004; Abe et al., 2006). Inadequate pressures combined with an insufficient total volume of BFR leg exercise (1 or 2 sets with a total of 20-30 repetitions) would be viewed by many BFR practitioners as a hindrance to substantial mCSA development. It is likely that the volume was too low to produce a substantial accumulation of metabolites which is seen to be an influential component to the adaptation process in BFRT (Loenneke et al., 2012a). The BFR pressure applied in combination with a lack of volume in BFR leg exercises would be the main factors in the minor increase of mCSA.

In comparison, Tarakeda et al. (2000a) administered a more effective protocol for developing a more potent hypertrophic response. The study analysed 11 participants who trained 2d/week over 16 weeks under an application of localised BFR which was more concentrated to just the subdominant bicep when compared to the Ishii et al. (2005) study. The training prescription contained 5 sets of 17.66 ± 1.5 repetitions which is a considerably large volume when compared to the training prescription by Ishii et al. (2005). The repetition range by Takarada et al. (2000a) was an average of completed set repetitions
which suggests the participants trained to failure. Training to failure is thought to be an essential component in the prescription of achieving optimal strength and mCSA adaptations when exposing participants to BFRT (Yamanaka et al., 2012). The training volume over a significantly longer period combined with a high BFR pressure resulted in a 20.3% increase in muscle hypertrophy. Despite obvious differentiation between the two muscle groups (thigh versus bicep), the data between the two studies is still very much contrasting. The two methods contained a control group which either did no training or were administered the same intensity without BFR. The control groups in both studies achieved no significant change, concluding that the BFR exposure was the primary cause of hypertrophy. The data presented from Takarada et al. (2000a) compared BFR at 30-40% 1RM and compared the intensity exposure (30-40% 1RM) without occlusion.

2.4 BFR versus TST

There are varying definitions of TST and can be defined as a modality which involves exercises that isolate specific muscles in order to increase strength more effectively and is often quantified in excess of 70% 1RM (McGill et al., 2009; Alcaraz et al., 2011). The study conducted by Takarada et al. (2000a) documented an 18.4% increase in bicep brachii mCSA in the TST group. However, the BFR group increased their mCSA by 20.3%, so therefore this study along with others within the literature comparing BFRT to TST, are suggestive of the novel prospect that BFRT elicits similar to greater adaptations when compared to TST.

Another study which has researched the difference between BFRT and TST was conducted by Cook et al. (2012) who concluded that there was a high level of activation of the higher threshold motor units (HTMU) when training under BFR which was similar to that of TST methods. The researchers found that high mechanical loading (70% of peak dynamic torque (PDT)) produced greater muscle activity than BFRT (20% PDT) before and after 8 recreationally active male participants underwent testing. However, despite BFRT demonstrating lower levels of muscle activation than TST methods; there were comparable torque decrements between the groups. Conversely, the participants weren't resistance trained. Therefore, unlike elite athletes, accessing HTMU would be substantially harder for untrained individuals (Walker et al., 2009).
The result of BFRT causes metabolite accumulation which leads to the recruitment of HTMU (Loenneke et al., 2011b); consequently there is enhanced endocrine activity as a result of HTMU augmentation (Abe et al., 2005; Madarame et al., 2008; Reeves et al., 2006; Tarakeda et al., 2000a). It is recognized that HTMU’s have the greatest potential for structural musculature morphology (Wagner, 1996). Many studies have researched BFR and electromyography (EMG) (Hotta et al., 2011; Wernbom et al., 2009; Yasuda et al., 2012; Manimmanakorn et al., 2013).

Manimmanakorn et al. (2013) assessed EMG activity and speculated that BFRT caused a shift in the recruitment pattern from type I to type II motor units during exercise. Furthermore this shift is possibly due to the stimulation of groups 3 and 5 afferents (Hayes et al., 2009). Consequently, the stimulation results in the suppression of the alpha motor neuron which innervates type 1 muscle fibers (Yasuda et al., 2010b). The study by Manimmanakorn et al (2013) suggested that this was caused due to a decrease in the concentration of oxygen in the BFR limb. Therefore, it can be suggested that the increase in strength found in the BFRT group can be attributed to HTMU inauguration of the already trained agonist muscles (Hakkinen et al., 1983). Despite the majority of data demonstrating similar to greater adaptations found in BFRT compared to TST, the samples used within the literature aren’t highly trained individuals and are certainly not from an elite population.

2.5 BFR and athletic populations

Elite populations are significantly harder to study in comparison to other populations. A major area in the BFR literature which needs to be addressed is whether BFR can specifically aid hypertrophy, strength and power development in elite athletes (Yamanaka et al., 2012). Firstly it is important to assess the characteristics elite athletes’ desire and to establish whether such characteristics have been developed already within the BFR literature. There is evidence of studies using highly resistance trained individuals and athletes but there are no definitions indicting an elite status of samples used. The present study defines the term of elite individual status as athletes who have competed nationally or internationally in the past 3 years and are currently training under a national governing body.
It is clear that BFR greatly increases musculature hypertrophy and strength. Researchers within the BFR literature suggest that the modality has an accelerated time course of adaptation compared to TST (Cook et al., 2013). However, muscular power is less studied. A study which has focused on just neuromuscular adaptations was conducted by Moore et al. (2004) who studied the effects BFRT at 50% 1RM over 8 weeks would have on untrained men who trained 2d/week. The data presented found a 22% increase in dynamic strength as well as a 51% increase in post activation potentiation (PAP), PAP is the result of musculature activation prior to an activity which produces increased levels of force generation (Esformes et al., 2011).

Force development and BFRT has undergone very little research. However, the current research has suggested that neural adaptations of strength are not conclusive enough to improve jump height performance (More et al., 2004). Such conclusions have also been drawn by Abe et al. (2005) who conducted a study considering the influence the effects BFRT would have on track and field college athletes but found no improvements in jump height after twice daily BFR exposure sessions over a period of 8 days. The study examined athletes who incorporated the training into their traditional sprint and jump training. However, a major limitation was that the athletes trained for a period of only 8 days which can be argued that a training study on such a time would not allow for developments in power adaptations. Conversely, the researchers documented a 10% increase in 1-RM leg press strength and estimated an increase in skeletal muscle-bone CSA of (4-5%). Despite combining BFR with traditional sprint, jump training and not conventional TST, the findings provide an insight into the effects BFR has on highly trained individuals. This at the time was a novel finding as these individuals are part of a population which do not readily obtain structural determinants easily (Hakkinen et al., 1987).

The findings found by Abe et al. (2005) were also found in a study conducted by Madarame et al. (2011) who conducted a 10 week training study. The study prescribed horizontal BFR squats 2d/week to examine whether this had an impact on jump performance but again failed to record any significant changes in increased jump height. This study examined untrained participants with no indication of the participants having any previous squat experience. However, the experimental design augmented a 19.3% and 8.3 increase in 1RM strength and mCSA. This study reflects the majority of research indicating increases in mCSA being the main adaptation, this lends itself to max force
production which suggests that BFRT may be less effective in terms of developing neural drive. Neural drive is associated with max rate-of-force development which is indicative of the research conducted within rehabilitation settings where movements tend to be performed in a more slow and controlled manner.

Recently a study conducted by Cook et al. (2013) examined 20 semi-professional rugby athletes on measures of strength, power and salivary hormonal parameters over a 3 week period. Athletes trained 3d/week during pre-season and participated in 5 sets of 5 repetitions bench press, leg squat, and pull-ups at 70% 1RM. The BFR group wore occlusive cuffs around their proximal thighs only, whereas the control did the same training intervention in a crossover design but without an occlusive stimulus. Once the training exposure had been completed, the BFR versus control groups were compared and it was found that improvements in squat (7.8 ± 2.1 vs 4.3 ± 1.4 kg), bench press (5.4 ± 2.6 vs 3.3 ± 1.4 kg), leg power (168 ± 105 vs 68 ± 50 W), salivary testosterone (ES 0.84-0.61) and cortisol responses (ES 0.65-0.20) were all greater in the BFR group. Despite greater results in the BFR group compared to the control the data provided is not compelling. If the results were more equivocal then BFRT would be a valuable stimulus during in season training when combined at intensities (70% 1RM) used in TST. However, the data is not suggestive of BFR being augmented with high loaded TST.

The results of Cook et al. (2013) demonstrate that despite lower body BFR, the group also achieved greater bench press 1RM strength compared to the control group. This study therefore is suggestive that a mechanism of a systemic origin assisted in the increase in upper body strength. Systemic mechanisms were also postulated in a study conducted by Yasuda et al. (2010a) who looked at how non-restricted trunk muscles are affected by multi-joint BFRT. The study included 10 participants in total, 5 of which underwent training twice daily, 6d/week for 2 weeks. The BFR group performed bench press at 30% 1RM with training consisting of 4 sets with repetitions equating to 75 in total. The study was a test-re-test experimental design with bench press 1RM strength, triceps brachii and pectoralis major muscle thickness being assessed pre- and post-intervention. The training intervention resulted in a significant increase in 1RM bench press strength in the BFR group (6%) but not in the control (-2%). Muscle thickness in the triceps and pectoralis major increased by 8% and 16% in the BFR group but not in the control group (-1% and 2%). The researchers suggest that the cause of non-restricted pectoralis major muscle hypertrophy observed in the non BFR chest muscle, was caused due to acute increases in
endogenous anabolic hormones such as growth hormone and insulin growth factor-1 (IGF-1). These suggestions derive from studies conducted by Abe et al. 2006 and Reeves et al. 2006.

Human growth hormone secretion is largely associated with exercise intensity and is modulated in greatest amounts during high intensity exercise (Kraemer et al., 2002). Conversely, BFR has been shown that the secretion of human growth hormone is equal to or even greater than that produced during TST which exceeds 70% non-restricted 1RM (Sato et al., 2005 and Reeves et al., 2006). However, despite consistent reports of increased levels of modulating growth hormone concentrations within the BFR literature, the direct role growth hormone plays, in regards to muscle morphology is equivocal (Cook et al., 2013). Contrary, It is better understood that exercise induced growth hormone production stimulates IGF-1 which directly impacts MPS and therefore impacting the rate of muscle morphology (Borst et al., 2001).

The work by Yasuda et al. (2010a) used few participants who were not resistance trained. However, there are studies which have assessed the application of BFR towards an athletic population (Abe et al., 2005; Takarada et al., 2002; Wernbom et al., 2009; Cook et al., 2012; Manimmanakorn et al., 2013). Conversely only two studies have claimed to have studied an elite population and such studies were conducted by Takarada et al. (2002) and Yamanaka et al. (2012). The study by Takarada et al. (2002) investigated 17 highly trained athletes who had over 5 years resistance training. The study included an 8 week training intervention where ‘elite’ rugby players participated in knee extensor muscle exercises at 50% 1RM with BFR (n=6), 50% 1RM with no BFR (n=6) and a control group which did no training (n=5). The results concluded that when averaged over all velocities, the strength increases of isometric torque after the training intervention were 14.3%, and 3.2% in the BFR and non-BFR groups. The increase in mCSA reported in the BFR group increased by 12.3%, whereas no results were reported for the non-BFR group. Despite low numbers of participants in each group the results provide evidence that BFR causes marked increases of mCSA and strength in ‘elite’ athletes. However, there is no definition of elite or to what level the rugby players played at so therefore, it is hard to determine the actual level of the participants, albeit highly trained.
Conversely, a study driven by Yamanaka et al. (2012) studied National Collegiate Athletic Association Division IA football players on determinants of muscular strength and hypertrophy. The participants (n=32) were separated into BFR (n=16), non-BFR (n=16) and trained 3d/week for 4 weeks. The intervention consisted of both groups, with or without BFR doing 1 set of 30 repetitions on bench press and squat at 20% 1RM, followed by 3 sets of 20 repetitions at 20% 1RM. The participants trained in their regular strength off-season training program which preceded the experimental interventions. The researchers found that the BFR intervention was effective for improving hypertrophy and strength during off-season conditioning. The results concluded that the average 1RM bench press increased by 7.0% in the BFR training group, which was significantly greater than the 3.2% increase in the non-BFR group. A significant difference was also seen in squat 1RM strength with the BFR group increasing on average 8.0% compared to 4.9% increase in the non-BFR group. However, in terms of hypertrophy only chest girth increased, whereas arm and thigh girths did not. Furthermore, the experimental interventions of BFR and non-BFR were carried out straight after the athlete’s regular strength off-season training program. Combining BFRT straight after a TST session may not be the most optimal approach in terms of developing hypertrophy and strength adaptations. It is important to recognise that there is a finite amount from which a muscle can adapt to a given training stimulus (Atherton and Smith, 2012).

The method administered by Yamanaka et al., 2012) did not have athletes train to exhaustion or failure. This could be the cause of no significant differences in arm and thigh girths after 4 weeks of exposure. Another factor influencing no significant change could be that the amount of BFRT exposures was insufficient. Conversely, the study analysed an athletic population on measures of strength and hypertrophy. This provided the scope of the present study of combining BFR-TST on measures of hypertrophy, strength, power and whether the combination of the two training interventions can cause positive outcomes on these determinants within an elite population.
CHAPTER III

METHOD
CHAPTER 3

METHOD

3.1 Experimental design

A total of 27 participants underwent a short term (7 week) training intervention where participants were randomly assigned into 3 groups, a TST group (10), BFR group (8), and a combined TST-BFR (9) group. The groups were designed to examine which training intervention would be most effective in developing the greatest functional muscle adaptations in elite athletes. To examine the possible training induced structural and neural changes, tests of anthropometry, vertical jump and 1RM tests were performed before and after training. Two groups were exposed to a BFR (BFR + TST-BFR) stimulus and performed leg press exercise at an intensity of 30% 1RM. The TST group were not exposed to BFR exposure and participated in their strength training method which was prescribed at an intensity of 80% 1RM and was very much orientated around strength adaptations. The same strength protocol was prescribed to the TST-BFR group, where they were also exposed to TST at (80% 1RM) which was administered by the athlete’s strength and conditioning coach. In order to supplement BFR with the TST protocol the TST-BFR group supplemented BFR 2d/week with their current TST training program. The TST and TST-BFR group engaged in the TST protocol 4d/week in a pre-competitive strength phase during the study. To ensure methodological validity, each athlete was assigned a consistent time to train by the strength and conditioning staff throughout the intervention period. The athletes who engaged in TST in both TST-BFR and TST groups were prescribed pre-competition strength training due to athletes competing in the commonwealth games. The study simulated the training environment where athletes prepared for a competition which in essence was post testing and therefore the study had strong ecological validity.

3.2 Participants

Thirty male (n=23) and female (n=4) elite athletes, [age 24 (5) year; height, 175 (6.8) cm; body mass, 73.2 (6.8) kg] volunteered to participate in this study. All athletes were of an elite status, competing at national, international level and were currently training under a national governing body. The inclusion criteria also required participants to have had experience in resistance training for over a minimum of 5 years. The participants were
randomly assigned into 3 groups: BFR (n=8), TST (n=9) and TST-BFR (n=10). Participants gave written consent to participate in the training study and were informed of the risks associated with the type of training. The consent was approved by the Ethics Committee of Cardiff Metropolitan University.

3.3 Height and body mass

The body mass index was calculated by dividing body mass (kg) by the square height (m). The measurement of body mass was conducted so to the nearest 0.1 kg using a Digital Scales (SECA- Model 770 Vogel & Halke, Hamburg, Germany). Participants wore light workout clothing with no footwear during the data collection. Height was measured using a stadiometer (Holtain Fixed Stadiometer, Holtain LTD, Crosswell, Crymych, Pembs, UK) to the nearest 0.1 cm (Louman et al., 1998).

3.4 Measurements of hypertrophy

Measures of hypertrophy were assessed using anthropometric tape which measured thigh girth circumference. Thigh girth was measured in centimetres and to the nearest 0.1cm around both legs. Thigh girth was measured in the plane orthogonal to the long axis of the thigh (Gobbo et al., 2012). A line was made from the superior edge of the patella to the inguinal crease and a mark was made at the midpoint of this measure. The anthropometric tape was then placed perpendicular to the long axis of the thigh around the point the mark was made (Louman et al., 1998).

3.5 Measurements of strength

Maximum dynamic leg press 1RM strength was measured prior to testing. Participants were allowed to warm up with a low load where 10-12 repetitions could be achieved comfortably. After a 2 minute rest the load was increased to an estimated 80% prediction of participant 1RM. Once a lift was completed successfully or when the participant used correct form and completed the entire lift in a controlled manner without assistance the load was increased by 5% until the participant failed to lift through the entire range of motion. A safety mechanism was in place between the participant and weight to ensure safety. Between sets a set period of 2–3 minutes of rest were given to the participants to ensure an adequate level of recovery was met (Abe et al., 2000).
3.6 Measurements of power

Counter movement jump height was collected using a jump mat (Smart jump, Fusion Sport, Brisbane, Australia) which assessed the levels of explosive muscular power during pre, post testing and therefore the nature of adaptations during the training intervention. Participants in all groups performed a counter movement jump 3 times with a 1 minute period of rest in between each jump. The highest jump achieved was used in the data analysis process.

3.7 Training protocol

One week prior to training participants engaged in an orientation session where force plate data, anthropometric measurements and isotonic 1RM strength tests were carried out for all subjects. Participants who were randomly assigned to either BFR or TST-BFR were made to become familiarised with training equipment. BFR and TST-BFR groups became accustomed to exercising under BFR, whilst experiencing the pressures used to restrict blood flow.

Participants performed 4 sets of dynamic bilateral leg press at 30% 1RM under BFR and were conformed to the guidelines set by Fahs et al. (2012). After the completion of individual sets participants were given 90\(^{\text{o}}\) of rest before proceeding onto subsequent sets and each session lasted between 15-20 minutes with time under BFR being between 8-10 minutes. A constant and controlled method was used throughout the prescribed training with intensity set at 30% of predetermined 1RM and volume consisting of 75 repetitions, 1\(^{\text{st}}\) set (30 reps), followed by a further 3 sets (15 reps). Once participants had finished the final set, the occlusive stimulus was maintained for a period of 2 minutes before the cuffs were removed, this was followed by an active cool down. The aim of the protocol was for participants to fail at the upper limit of the rep range, if the participant completed the session without failure then verbal feedback would enable for adequate loading during the next session.

Repetitions consisted of all participants following the same protocol, initiating the movement began with a deep breath and held during the descent phase until a depth where the greater trochanter of the femur was lowered to an equal level to the knee and therefore parallel to the leg press plate (McGuigan and Winchester, 2008). As soon as the required depth had been reached the investigator delivered verbal feedback to the
participant and once received the accent phase began with a maximal and forceful movement was initiated in order to engage the high end motor units (Gullich et al., 1996; Young et al., 1993). Participants engaged in training with at least 24 hours in between sessions.

3.8 Blood flow restriction

During the orientation session, one week before training, the TST and TST-BFR groups were trained to wear an occlusive stimulus (Manual Blood Pressure Monitor, Yamasu, Tokyo, Japan) at the most proximal portion of the upper legs. The blood pressure devise was inflated between 120-200 mmHg (Fahs et al., 2011) depending on limb circumference. The participants were told that the pressure should be tight but not at all painful and it should be the build-up of metabolites causing the pain and not the blood pressure devise itself, this resulted in a varied range in the pressures applied. Once an appropriate pressure was found this pressure was maintained throughout the entire session. Due to the nature of the devise, during working sets the pressure would deviate by roughly 5%. However, during inter-set rest times the occlusive cuff was pumped to the desired pressure.

3.9 Rating of Perceived Exertion (RPE) and Rating of Perceived Sensation (RPS)

During the training protocol, after all 3 groups (BFR, TST, TST-BFR) performed each subsequent set; RPE was assessed with a customised Borg scale. The customised Borg RPE scale provides greater validity as colour, emoticon, verbal cues are used and previous studies have shown this method to be more effective than other RPE measures (Bijur et al., 2001 and Bulloch et al., 2009). The method used is comparable to Borg’s RPE original method (Borg, 1998), however the participants were asked to look at a customised chart and point on the scale instead of calling out a number.

RPS unlike RPE, was conducted after each set. The participants were asked to rate the sensations of pressure, burning, aching, and pins/needles in their legs and surrounding areas of the BFR devise. This method was devised by Weatherholt et al. (2013) and used a modified Borg CR-10 pain scale with the addition of colour and emoticons which has been found to be most effective by individuals engaging in BFR.
Figure 2. A visual analog developed by Weatherholt et al. (2013) to analyse athlete rate of perceived exertion and rate of perceived sensation. The scale was utilised throughout the data collection process to assess the BFR and TST-BFR group RPE and RPS.

3.10 Statistical Analysis

The statistical process of analysing the data and training variables was analysed using statistical software (IBM SPSS 20; IBM Corp, New York, Armonk). The three training interventions were analysed by an ANOVA, followed by post hoc testing using Bonferroni’s method and the statistical significance was set at an alpha value of (p<0.05). Cohen’s effect size was used to determine the magnitude of the partial eta-squared values ($\eta^2$s).
Figure 2. Schematic representation of the studies experimental design.
CHAPTER IIII

RESULTS
CHAPTER 4

RESULTS

There was no significant difference (p > 0.05) in height or weight in any of the training interventions (Table 1).

Table 1. Physical characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>TST Pre</th>
<th>TST Post</th>
<th>BFR Pre</th>
<th>BFR Post</th>
<th>TST-BFR Pre</th>
<th>TST-BFR Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>173.9 ± 5.3</td>
<td>173.7 ± 5.8</td>
<td>177.4 ± 6.8</td>
<td>177.2 ± 5.4</td>
<td>173.7 ± 6.7</td>
<td>173.9 ± 6.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.8 ± 7.1</td>
<td>173.7 ± 5.9</td>
<td>74.1 ± 6.4</td>
<td>74.5 ± 7.4</td>
<td>72.9 ± 6.3</td>
<td>73.2 ± 5.9</td>
</tr>
</tbody>
</table>

Note: Values are mean with standard deviation (SD).

4.1 Changes in thigh girth

The mCSA [left] and mCSA [right] increased significantly (p < 0.01) in the TST group (Table 2). The significant change was seen between pre- and post-test where the TST group increased mCSA [left] by (1.4cm/2.3%) and mCSA [right] by 1.8cm/2.9%). The BFR group increased mCSA [left] and mCSA [right] by (2.1cm/3.7%), respectively. The increased change in thigh girth in the BFR group was of significance (p < 0.01). The TST-BFR group also had a significant increase (p < 0.01) in mCSA [left] and mCSA right]. The mCSA [left] increased significantly by (3.0cm/4.8%) and mCSA [right] by (3.3cm/5.2%), respectively.

Table 2. pre- and post-test data of strength, power and girth measures by training intervention.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TST Pre</th>
<th>TST Post</th>
<th>BFR Pre</th>
<th>BFR Post</th>
<th>TST-BFR Pre</th>
<th>TST-BFR Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>mCSA [Left] (cm)</td>
<td>59.2 ± 3.2</td>
<td>60.6 ± 3.4*</td>
<td>54.4 ± 4.9</td>
<td>56.5 ± 5.1*</td>
<td>58.9 ± 1.8</td>
<td>61.9 ± 1.9*</td>
</tr>
<tr>
<td>mCSA (Right) (cm)</td>
<td>59.3 ± 3.5</td>
<td>61.1 ± 3.7*</td>
<td>55.0 ± 5.0</td>
<td>57.1 ± 5.2*</td>
<td>59.2 ± 2.4</td>
<td>62.5 ± 2.4*</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>38.7 ± 10.0</td>
<td>39.9 ± 10.1</td>
<td>39.3 ± 6.6</td>
<td>39.8 ± 6.3</td>
<td>34.2 ± 4.1</td>
<td>35.9 ± 4.3</td>
</tr>
<tr>
<td>1RM Leg press (kg)</td>
<td>317.2 ± 54.5</td>
<td>337.2 ± 57.7*</td>
<td>99.0 ± 57.7</td>
<td>320.2 ± 61.8*</td>
<td>302.0 ± 83.0</td>
<td>341.9 ± 94.5*</td>
</tr>
</tbody>
</table>

Note: Values are mean with standard deviation (SD). * Significant difference (p < 0.05).

The within subject test for mCSA [left] indicated that irrespective of group, the main effect for time was significant (F_{1,2} = 49.4, p < 0.01). The main effect for mCSA [right] was also significant (F_{1,2} = 39.1, p < 0.01). The change in performance, over time per group indicated that the group*time interaction was significant (p < 0.01) for mCSA [left] and
Post hoc analysis using the Bonferroni test demonstrated that the mCSA from pre- to post-test was significantly different (p< 0.05) between TST and BFR intervention. The BFR and TST-BFR intervention was also significantly different (p< 0.05). The TST and TST-BFR groups demonstrated no significant difference (p> 0.05) between the two training interventions. The mCSA post hoc analysis using the Bonferroni test indicated no significant difference (p> 0.05) between, TST, BFR and TST-BFR groups.

4.2 Changes in 1RM strength

The 1RM strength improved significantly (p< 0.01) in the TST group (Table. 2). The significant increase was seen between pre- and post-testing where the TST group increased 1RM strength by (20kg / 6.0%). The BFR group also improved 1RM strength significantly (p< 0.05) and increased 1RM strength by (21.2kg/6.6%). The combined TST-BFR group increased 1RM strength by (39.9kg/11.7%) and was significantly different (p< 0.05) between pre- and post-testing.

The within subject test for 1RM strength demonstrated that irrespective of group, the main effect for time was significant ($F_{1,2} = 17.7$, p< 0.01). The change in performance, over time per group indicated that the group*time interaction was significant (p< 0.01) for 1RM strength. Post hoc analysis using the Bonferroni test demonstrated that 1RM from pre- to post-test was not significantly different (p> 0.05) between TST and BFR intervention. The BFR and TST-BFR intervention was not significantly different (p> 0.05). The TST and TST-BFR groups also indicated no significant difference (p> 0.05) between the two training interventions.

4.3 Changes in countermovement jump height

The CMJ height improved in the TST group between pre- and post-testing by (1.2cm/3.0%). However, this was achieved with no significance (p> 0.05) (Table. 2). The BFR group increased CMJ height by (0.5cm/1.2%). However, the increase in height had no significant value (p> 0.05). The TST-BFR group also had no significant difference between pre- and post-testing with increases of (1.7cm/4.7%). The within subject test for CMJ height indicated that irrespective of group, the main effect for time was not significant ($F_{1,2} = 0.1$, p> 0.05). The change in performance, over time per group indicated that the group*time interaction was not significant (p> 0.05) for 1RM strength.
4.4 Training variable effect size in TST, BFR and TST-BFR groups

The effect size as seen in (Table. 3) demonstrates the magnitude in effects size the training interventions had on training variables. The mCSA [left] signified a large effect size ($\eta^2$s > .8) for groups TST, BFR and TST-BFR. The mCSA [right] for groups TST, BFR, and TST-BFR had a large effect size for all groups ($\eta^2$s > .8). The effect size for 1RM strength also showed a large effect size ($\eta^2$s > .8) for groups TST, BFR and TST-BFR. The BFR and TST-BFR demonstrated low effect sizes for CMJ height ($\eta^2$s < .2) with the TST group showing a moderate effect size ($\eta^2$s > .2).

4.5 RPE and RPS scores

The RPE scores for BFR and TST-BFR groups were not significantly different ($p< 0.05$). The mean RPE scores for the BFR and TST-BFR group during the warm up was (8.1 and 8.8), respectively. The first set (30 repetitions) generated RPE scores (for BFR and TST-BFR (12.5 and 11.9). The RPE after the second set (15 repetitions) provided scores of (14.8 and 15.6) for the BFR and TST-BFR groups. The third set (15 repetitions) collated scores for the BFR and TST-BFR group of (17.4 and 17.0). The final set (15 repetitions) generated RPE scores of (18.7 and 18.3) in the BFR and TST-BFR groups. The means were averaged over each of the 14 BFRT exposures. The RPS data seen in (Appendix. 2) demonstrates the mean recordings of all subjects who participated in the BFR and TST-BFR groups, respectively. The average BFR session RPS did not increase significantly throughout the training interventions. However, the athletes did experience a somewhat strong pressure and aching sensation throughout the BFR exposures. Burning was also a moderate sensation experienced with a somewhat very weak experience of pins/ needles.

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**Table 3.** Effect size on pre- to post-test training variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>TST Effect size ($\eta^2$s)</th>
<th>BFR Effect size ($\eta^2$s)</th>
<th>TST-BFR Effect size ($\eta^2$s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mCSA [Left] (cm)</td>
<td>.862</td>
<td>.923</td>
<td>.964</td>
</tr>
<tr>
<td>mCSA [Right] (cm)</td>
<td>.895</td>
<td>.912</td>
<td>.964</td>
</tr>
<tr>
<td>Countermovement jump (cm)</td>
<td>.021</td>
<td>.004</td>
<td>.033</td>
</tr>
<tr>
<td>1RM Leg press (kg)</td>
<td>.738</td>
<td>.717</td>
<td>.907</td>
</tr>
</tbody>
</table>

Note: Results generated by Partial eta Squared ($\eta^2$s).
CHAPTER V
DISCUSSION
CHAPTER 5
DISCUSSION

5.1 Main findings

The purpose of the present study was to examine the effectiveness 7 weeks of varying training interventions would have on muscular hypertrophy, strength and power in elite athletes. Furthermore, due to the difference in group training exposures, a secondary question postulated the effects a dose type response would have on the three performance measures. Training exposures were administered to the TST group (28), BFR (14) and TST-BFR (42). The results of the present study support the original hypothesis that all training interventions would have a significant effect on changes in muscle hypertrophy and strength. However, the present study does not support the hypothesis that the TST and TST-BFR training interventions would improve power. Furthermore, data from the present study supports the integration of BFRT into a TST program. Combining TST and BFRT was an effective intervention in providing significant increases in muscular hypertrophy and strength. Additionally, it was hypothesised that BFRT would be an effective short term stimulus which elite athletes could utilise to achieve significant developments in muscular hypertrophy and strength. This hypothesis of BFRT providing elite athletes with quick time course adaptations was evident in the present study.

5.2 BFRT intervention

The present study can be considered novel in the respect that all athletes were of an elite status compared to previous studies which have investigated BFRT (Abe et al., 2005; Abe et al., 2006; Cook et al., 2007; Fujita et al., 2007; Madarame et al., 2008; Reeves et al., 2006; Takarada et al., 2000; Yasuda et al., 2006). However, despite an elite training status, the BFR group (30-50% 1RM) significantly increased (p< 0.01) mCSA (2.1cm/3.7%) and a concomitant increase (p< 0.01) in 1RM strength (21.2kg/6.6%). The significant changes observed are relatively high considering the athletes were of an elite training status and would have already obtained a high degree of musculature hypertrophy and strength. The increase would not have been achieved at intensities as low as 30-50% 1RM without BFR (Yamanaka et al., 2012). It can therefore be suggested that BFRT can indeed be an effective stimulus for elite athletes. However, it is important to consider the varying training exposures the athletes were prescribed BFRT over the 7 weeks. The BFRT
group were exposed to just 14 sessions which is a small dose of training but caused a significant increase in mCSA and strength.

Administering minimal training exposures and achieving significant changes in muscle adaptation enables athletes to become exposed to an accelerated super-compensatory training intervention (Abe et al., 2005). Decreasing the time athletes achieve the super-compensatory phase of training is accelerated when the training exposure elicits minimal fatigue and recovery (Mitsumune et al., 2013). The athletes were given an effective training stimulus whilst obtaining sufficient rest in-between training sessions (Kraemer, 2000). Minimal fatigue and recovery is evident in the BFR literature (Abe et al. 2005), despite early literature suggesting inflammation and muscle damage is a product of BFRT which causes acute increases in cell swelling (Yasuda et al., 2010). Additionally, the aforementioned mechanism as previously mentioned in the study can be influenced by other factors other than muscle trauma and inflammation. During the present study, the nature of BFRT would have caused hypoxic conditions, distal to the occlusive stimulus. The hypoxic environment within the exercising muscles would have increased the levels of intracellular metabolites (Colgan et al., 2012). Intracellular metabolites would have created an increased osmotic gradient which would have transiently increased muscle cell volume, signalling an anabolic response (Loenneke et al., 2012b).

The present study utilised the method of prolonging BFR after BFR. This was done to fully exploit the reactive hyperemia response and increase the extent of metabolite accumulation. However, it is important to note that despite increasing the reactive hyperemia mechanism, hepatocytes have a finite ability to increase in cell volume (Calloe et al., 2005). Therefore, prolonging BFR may not have increased an anabolic response further than removing the occlusive stimulus immediately post exercise. However, reactive hyperemia induced muscle cell swelling during BFRT has been postulated to cause the activation of mTORC1, MAPK signalling pathways (Thiebaud et al., 2014) and inhibit catabolic mechanisms; this would inherently alter the protein balance towards anabolism (Loenneke et al., 2012b) causing muscle hypertrophy in the BFR group. Mechanisms such as cell swelling have been suggested to be influential to BFR induced adaptations within a short period of training exposure (Thiebaud et al., 2014). Providing an effective stimulus with minimal exposure to training could potentially aid athletes becoming exposed to overtraining.
Overtraining is a serious issue for many athletes, with many seasonal competitors generally avoiding high intensity strength interventions during competitive periods to circumvent overtraining (Abe et al., 2005). Therefore, BFRT could be a beneficial stimulus to athletes who have to tolerate high levels of training intensity with heavy loading during competitive periods. Recovery time is directly correlated to the likelihood of overtraining (Kellman, 2010). However, BFR causes less muscle damage than TST, whilst obtaining comparable physiological adaptations (Takarada et al., 2000). Consequently, it can be suggested that the present study demonstrated an effective stimulus which elite athletes can implement through their training program on days where a psychological break and recovery from high intensity TST is needed. In addition, It has been suggested that TST would not have readily caused a marked increase in musculature size and strength in athletes in such a short time scale compared to BFR (Abe et al., 2005; Hakkinen et al., 1987; Takarada et al., 2002; Yamanaka et al., 2012).

5.3 TST intervention

Conversely, the TST group did in fact achieve similar results to that of the BFR group despite suggestions otherwise. The TST group significantly increased (p< 0.01) mCSA (1.6cm/2.6%) and strength (p< 0.01) (20kg/6.0%). However, it would be misleading to state that this was achieved similarly to the BFR group. The TST group participated in twice as many training sessions as the BFR group (28 vs 14). Therefore, it can be suggested that in terms of achieving increased mCSA and strength that comparable, if not greater levels of physiological adaptations can be achieved with half the training exposures when doing BFRT compared to TST. This also points towards BFRT having a quicker time course to adaptation compared to TST. Quicker time course to adaptation observed in BFRT compared to TST could be due to increased levels in endogenous hormones observed in BFR research compared to TST. Plasma concentrations of GH after TST have been found to increase by a 100-fold (Kraemer et al., 1990) compared to a 290-fold increase after BFRT (Takarada et al., 2000a). The greater endogenous response observed in BFRT could possibly have caused the greater effect size observed in the BFR group in the present study.

However, that does not suggest that over longer periods, BFRT would be more effective at producing increased mCSA and strength further than TST. More research is needed to better understand BFRT and warrants further exploration. Research into BFRT is continuously emerging with awareness of the training protocol ever increasing throughout
scientific research, orthopaedics and the fitness industry. This has steered a section of the research to explore the next progression of comparing BFRT to TST. Therefore, this study took this progression a step further. The present study not only compared but also contrasted the effects of BFRT and TST to see whether BFR can be supplemented with TST.

5.4 TST-BFR intervention

The data presented from this study demonstrates that 7 weeks of TST-BFR caused a significant (p< 0.01) increase in mCSA (3.2cm/5.1%) and strength (39.9kg/11.7%). The data presented suggests that TST can in fact be combined with BFR effectively. Moreover, it can be suggested that if an athlete does BFRT on its own, TST on its own or supplements both interventions together then that athlete can expect to see an increase in mCSA and strength. Additionally, that athlete may get a greater effect by combining TST-BFR. However, in the construct of a competitive season, if an athlete can achieve a significant improvement in strength and mCSA from just 14 sessions vs 42, the difference in effect size increase in strength by 21.2kg or an increase in strength by 39.9kg comes down to whether an additional 18.7kg improvement in the mean is worth a further 28 sessions.

Conversely, an athlete can never be too strong in terms of desiring the greatest strength adaptations. In that regard the data demonstrates a greater significant increase in strength from the TST-BFR group. However, whilst the data has not shown a significant improvement (p> 0.05) in power, the TST training was a strength orientated mesocycle. There is a compelling amount of data to suggest that strength is correlated to increased levels of power (Aagaard et al., 2002; Baker et al., 2001; Cormie et al., 2010). Furthermore, it could be that the athletes who participated in the TST-BFR group could well achieve a greater carry over effect when transferring over to a power phase in their training program. This can be suggested because the athletes built up more strength, which could lead to an experience in a delayed training effect for rate of force development. Additionally, because the training program was geared around strength, then strength was the specific adaptation. The specific adaptations imposed demands principle (SAID) states that a muscle will adapt to the imposed demands (Bandy and Saunders, 2001). Furthermore, the TST-BFR group were prescribed more training exposure than the other groups. Despite increased exposure, it is important to note that
because of the relationship between strength and power, a knock on effect in the next mesocycle block could elicit greater enhancements in power.

There was a significant difference ($p < 0.01$) in mCSA between pre and post testing. However, there are limitations to the procedures of obtaining mCSA. Anthropometric tape was used so therefore the increased measure of thigh girth does not give an insight of the composition of the change. The increase in mCSA only demonstrates an insight to structural changes because there was no significant difference ($p > 0.05$) in power development. However, it can be suggested that increased mCSA was evident due to architectural as opposed to neural changes. Architectural changes can only be assumed because in the present study there was no mechanical assessment of pennation angle, muscle size or tendon size and therefore architectural change can only be suggested. Similarly, it can be suggested that adaptive neural changes were not a product of any of the prescribed training interventions. This can be suggested because there was no significant improvement in power, which is suggestive in terms of rate coding, motor unit recruitment and firing frequency that these neural components did not necessarily come into effect.

5.5 Comparison of training intervention

The data presented demonstrates that all three interventions significantly increased ($p < 0.01$) mCSA and strength. However, a compelling amount of data suggests that a change in strength as a result of TST is due to neural adaptations (Arazi et al., 2013; Schoenfeld, 2010; Zarezadeh-Mehrizi et al., 2013). Conversely, it can be suggested that the predominant change as a result of BFRT is due to structural changes. However, it is unclear what the underpinning physiological adaptations that BFRT elicits (Loenneke et al., 2011b).

In the present study it can be suggested that BFR and TST produced architectural muscle changes due to the significant increases ($p < 0.01$) in mCSA. However, it cannot be suggested that either TST or BFR group developed any neural adaptations due to no significant difference ($p > 0.05$) in power. However, there is a compelling amount of data suggesting TST provides neural adaptations (Arazi et al., 2013). Conversely, there is evidence to suggest that marked increases in mCSA and strength seen in BFRT, despite low level of force generation, is due to HTMU’s becoming exposed during training (Yasuda et al., 2004). It is evident from the present study that both modalities can be
utilised together as part of an effective training program. The TST-BFR group despite greater exposures demonstrated the greatest results in terms of increases in strength and mCSA. It can be suggested that a combination of neural and structural adaptations would be augmented during a combined training intervention despite the present study suggesting otherwise. Conversely, combining both approaches would be viewed as optimal as it can be suggested that an athlete would obtain both structural and neural adaptations, whilst achieving a large mCSA and strength effect.

5.6 BFR effects on RPE and RPS

It is apparent that from the range of SD of subject RPE (Figure. 3), athlete perception and tolerance is diverse with many athletes achieving ratings similar to untrained subjects in previous studies (Hollander et al., 2010; Wernbom et al., 2006; Wernbom et al., 2009; Weatherholt et al., 2013). Therefore, from this data it can be concluded that the RPE from BFRT is not different between populations and not dependant on training status. However, it should be noted that during the present study the load was progressively increased to ensure that repetition ranges were attained and achieved with maximal effort. When comparing protocols where athletes trained at a constant BFRT intensity throughout training compared to protocols where there was a linear progression of 1RM training intensity it is apparent that linear progression of percentage 1RM is more desirable as it ensures training until failure (Moore et al., 2004; Takarada et al., 2000b; Takarada et al., 2002; Takarada et al., 2004). There is evidence to suggest that when BFR percentage 1RM is maintained, decreases in RPE ratings are seen and this is due to improvements in metabolic adaptations such as increased concentrations of myoglobin and increased mitochondrial activity that occur with hypoxic training (Manimmanakorn et al., 2013). However, as seen in the present study, athlete endeavour was continuously challenged which reflects the constant high RPE documentation and this was not a novel method used in the present study (Karabulut et al., 2010; Karabulut et al., 2011). Furthermore, another reason for the progression was due to the validity of the 1RM test. During pre-test 1RM tests, it is not certain that the results were a true reflection of athlete's absolute 1RM.

The present study based the research around practical applications which athletes could use. Furthermore, the application of an occlusive stimulus in the present study appeared to achieve a desirable BFR pressure based on RPE and RPS scores. However, it has been suggested that BFRT would be limited and would not appeal to highly motivated athletes (Wernbom et al., 2008). Moreover, exercise intensity has been shown that exceeding
comfort zones during exercise results in poor adherence (Williams et al., 2008). Conversely athletes constantly push through their comfort zones in training sessions (Almagro et al., 2010) and despite high RPE scores the RPS ratings would suggest that athletes coped well with the occlusive stimulus with no real factor apart from pressure causing too much of a concern. The present study demonstrated an effective way for athletes and coaches to track perceptual effort and pain which is in conjunction with Hollander et al. (2010). Furthermore, this study recruited a sample size which was greater than the majority of that seen in the BFR literature (Abe et al., 2005; Abe et al., 2006; Fujita et al., 2007; Madarame et al., 2008; Reeves et al., 2006; Sakamaki et al., 2008; Sato et al., 2005; Takano et al., 2005; Takarada et al., 2000; Yasuda et al., 2006) and therefore can be considered as being high in validity.

5.7 Practical implications

It can be suggested that if an athlete does BFRT on its own, TST on its own or supplements both interventions together then that athlete can expect to see an increase in mCSA and strength. Additionally, a greater effect can be achieved by combining TST-BFR. However, utilising the approach from the present study needs to be done with caution as different training exposures were used. Therefore, in the construct of a competitive season, if an athlete can achieve a significant improvement in strength and mCSA from just 14 sessions vs 42, the difference in effect size increase in strength by 21.2kg or an increase in strength by 39.9kg comes down to whether an additional 18.7kg improvement in the mean is worth a further 28 sessions.

Moreover, due to the time course of adaptations suggested in BFRT and adaptations in mCSA and strength being achieved quicker than TST, it could be argued that vascular angiogenesis may not occur on such a short time scale. Therefore, if an athlete was to use BFRT in isolation then TST or TST-BFR should be resumed to elicit vascular adaptations. Additionally, despite no study suggesting this method, it is well documented that TST increases angiogenesis (formation of new blood vessels) (Gavin et al., 2007). Furthermore, the adaptations obtained in mCSA and strength from just 14 sessions of BFRT can provide athletes with an effective stimulus that can be utilised when coming back from a long period of no training or injury. This study has provided data to suggest that only 14 exposures can provide a large effect on increases in mCSA and strength with low mechanical stress.
The present study demonstrated an effective stimulus which athletes can implement through their training program. Furthermore, it can be suggested that BFRT could be used on days where a recovery from high intensity TST or perhaps a psychological break from TST is needed. Additionally, the present study demonstrated an effective way for athletes and coaches to track perceptual effort and pain which is in conjunction with Hollander et al. (2010).
CHAPTER VI

CONCLUSION
CHAPTER 6

CONCLUSION

6.1 Main findings

In conclusion, training induced increases in thigh girth and 1RM dynamic strength can be achieved significantly when training under a TST, BFR and combined TST-BFR intervention. The results in the present study suggest that 14 BFRT exposures over a period of 7 weeks can significantly improve musculature hypertrophy and strength in elite athletes. Acknowledging the differences in exposures, athletes can achieve similar musculature adaptations when combining exercise with BFR in comparison to TST but with half the training exposures. This is a valuable stimulus athletes can accentuate and utilise during a competitive season. Furthermore, BFR and TST can be combined effectively to enhance performance measures without a said given loss in performance. However, with such an increase in performance measures, it is achieved at the cost of significantly more training exposures. The combined training intervention would have initiated a neural, hormonal and metabolic influence in achieving the aforementioned adaptations (Takarada et al., 2002). In order to get a greater perspective of which intervention is more effective in improving performance measures, an equal amount of training exposures need to be prescribed. However, the reason the present study did not do this was because the focal point of the research was directed towards athlete’s performance levels versus a dose type response in training exposures. Furthermore, the training modes were successful in improving mCSA and strength. However, the same is not true for power. It can be suggested that there was no significant improvement in power due to insufficient training stimulus or a lack of power-orientated exercise selection.

6.2 Limitations of the study

A limitation of the present study is that obtaining the mCSA and strength performance measures was obtained using a 1RM leg press machine and anthropometric tape. Utilising these methods can only give an insight and not a true reflection of the changes that have occurred physiologically. Additionally, another limitation is that body composition was not assessed and therefore differentiation during thigh girth measurement cannot be said to have been due to increased muscle morphology. Furthermore, the exposures administered to the groups were different which doesn’t allow the question to which intervention is more effective to be answered. However, this method was an important
area to research in terms of developing an effective training system. This system provides an insight athletes can use and implement into their training programs to develop the greatest training stimulus. Another limitation to the present study is that the occlusive cuff was not a purpose built devise to provide BFR. However, the cuff provided an effective method for controlling pressure and provided an effective stimulus for eliciting adaptations in mCSA and strength.

6.3 Future directions for research

Future research should focus on the effectiveness BFRT has during different stages of an athlete’s periodization program. Such periods include, pre-season, de-loading and recovery periods. Furthermore, research should investigate whether the combination of TST-BFR has a delayed carry-over effect on developments of power as this was an area not evident in the present study. Moreover, research should focus on developing a follow up study to analyse whether adaptations achieved as a result of BFRT are sustained after a washout period. This should be conducted on BFRT in isolation or during a combined intervention as done in the present study. The effect BFRT has on arterial sheer stress is poorly understood and research should focus on the vascular adaptations of the training modality. Studying vascular adaptations in combination with BFRT would provide an insight into whether BFRT adaptations can be sustained. Moreover, the mechanisms behind the adaptations caused by BFRT are under researched and needs further investigating. A longitudinal study should assess the long term implications of chronic BFRT training over a prolonged period, assessing the safety and adaptations the intervention elicits.
CHAPTER VII

REFERENCE LIST


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activity participation 6 and 12 months later. Psychology in Sport and Exercise. 9, (3) 231–245.


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CHAPTER VIII

APPENDICES
Date: 17/02/2014

To: Daniel

Project reference number: 13/05/168U

Your project was recommended for approval by myself, as supervisor prior to the project starting on November 18th, 2013.

Appendix 1. Ethics status

Yours sincerely

RSL

Supervisor
Appendix 2. BFR session plan.

<table>
<thead>
<tr>
<th>Time</th>
<th>Load (kg)</th>
<th>Set</th>
<th>Repetitions</th>
<th>BFR pressure (mmHg)</th>
<th>Rest</th>
<th>RPE</th>
<th>RPS</th>
<th>Notes</th>
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<td>0</td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td>Set load/Brief participant/Do not apply device/Warm up</td>
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<td>1</td>
<td></td>
<td>1</td>
<td>Warm up</td>
<td>10-15</td>
<td>90</td>
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<td>(Non BFR)</td>
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<td></td>
<td></td>
<td></td>
<td>Brief participant/Apply BFR device/Working sets</td>
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<td>8</td>
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<td>Remove BFR device/Cool down</td>
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<td>6</td>
<td>Cool down</td>
<td>10-15</td>
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Appendix 2. A visual analogue to measure athlete’s rate of perceived sensation.

Weatherholt et al. (2011)