Hypoxic resistance training in elite Rugby Union athletes

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Abstract

Limited research suggests that muscle adaptations may be enhanced through resistance training in a hypoxic environment. Altitude training has been integrated into athlete preparation strategies for the past five decades by elite athletes, with the goal of improving performance. Simulated altitude modalities allow athletes the ability to live low (sea level) and train high (completing training sessions at altitude) to enable, intermittent hypoxic exposure (IHE) training paradigm to optimize adaptation and performance. The first part of this thesis reviews the literature on different methods of hypoxic training and how this may be implemented into the sport of Rugby Union. Part two of the thesis includes an original investigation whereby 17 professional Rugby Union athletes (age [mean ± SD], 24 ± 3 years; body mass, 98.7 ± 12.8 kg, height; 188.9 ± 7.9 cm), performed 12 resistance training sessions over a three-week period. Participants were randomly divided into two groups: HYP (n=8) where resistance training sessions were performed in an environmental chamber with O_2 concentration maintained at ~14.4% (~3000m simulated altitude), or CON (n=9) identical resistance training sessions were performed without the simulated altitude (O_2 = 20.9%, at sea level). The research assessed pre and post-test measures of strength, power, endurance, speed and body composition. Analysis revealed a *small* positive effect for bench press (d = 0.24), weighted chin-up (d = 0.23) and bronco endurance tests (d = -0.21) in the HYP group when compared to the CON. In conclusion, resistance training in a hypoxic environmental chamber may lead to small improvements in upper body strength and endurance compared to the same training performed at sea-level. These findings are somewhat novel, given the short timeframe of the study and the elite population sampled. This study adds new practical information for athletes, coaches and practitioners on the effects of resistance training in a hypoxic environment on strength trained, professional team sport athletes.

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Abbreviations

CI - Confidence interval

cm - Centimeters

CMJ - Countermovement jump

CON - Control

CV - Coefficient of variation

ES - Effect size

HYP - Hypoxic

IHRT - Intermittent hypoxic resistance training

Kg - Kilogram

min - Minute

M - Meters

RPE - Rate of perceived exertion

1RM - One repetition maximum

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Thesis Overview

The format of this thesis includes a chapter presented in the style of an individual journal article in its published format and consequently, some information may be repeated. The thesis is comprised of three chapters. Chapter One contains a review of literature and introduces the reader to rugby union, hypoxia, and the concept of using hypoxia to aid athletic performance. Chapter Two investigates the effect of resistance training in a hypoxic chamber on physical performance in elite rugby athletes. This chapter appears in the same format that was required by the journal *High Altitude Medicine and Biology* where it has been published. The final chapter, Chapter Three, summarises the overall findings of the main experimental study included in this thesis and provides both practical applications and suggested areas for further research.

Chapter One:

Literature Review

Part One - Physical demands of Rugby Union

Rugby Union is a high-intensity team sport played by multiple countries throughout the world (Duthie, Pyne, & Hooper, 2003). Teams compete to score a superior amount of points which are awarded based on a series of actions (tries, conversions & penalties) and played over two 40 minute halves separated by a break of no longer than 10 minutes (Cahill, Lamb, Worsfold, Headey, & Murray, 2013; Duthie et al., 2003). In order for rugby to remain attractive to spectators and be competitive with other football codes, rugby has experienced numerous law changes. Austin, Gabbett, and Jenkins (2011) suggest that these law changes have meant that the game has become faster and more physically demanding as a result. This has included rapid changes in the fitness profile and movement demands of elite players (Duthie et al., 2003). Players compete and contest in frequent bouts of high-intensity activity (running, passing, tackling) separated by lower intensity activity (standing, walking & jogging). The movement demands of Rugby Union are considered unique in nature and players have a diverse range of locomotive demands related to their positional group (Waldron, Twist, Highton, Worsfold, & Daniels, 2011).

The game involves two teams of fifteen players made up of two positional groups consisting of eight forwards and seven backs. These positional groups can then be further divided into sub-positions. For example, within the eight forwards there are three front-row, two middle-row and three back-row positions. The back division consists of two inside backs, two midfield backs and three outside back playing positions (Duthie et al., 2003). Each of the positional groups requires a broad range of physical, physiological and skill based attributes (Duthie et al., 2003). Outside backs require considerable amounts of speed to out-manoeuvre their opponents and cover substantial space in the shortest possible time while covering the defensive line. In stark contrast, the front row positions demand large amounts of lower body and upper body strength in order to contest for the ball in close contact situations and challenge the opposition at scrummaging.

Differences in movement demands have been reported between backs and forwards in rugby players with front row (5136m), second row (5755m) and back row (6038m) athletes covering considerably less distance than the scrum half (7098m), inside backs (6545m) and outside backs (6276m) (Cahill et al., 2013; Deutsch, Maw, Jenkins, & Reaburn, 1998; Quarrie, Hopkins, Anthony, & Gill, 2013). Similar results were found when examining high intensity (>20 kilometers per hour) running distance. Researchers (Quarrie et al., 2013) reported that the front row (170m), second row (270m) and back row (380m) covered less high intensity distance than the scrum half (480m), inside backs (480m) and outside backs (480m). Other running metrics such as distance per minute of game time (total match distance divided by total match time), maximum velocity reached during match play (kilometers per hour) and number of accelerations (meters per second) also showed similar trends when comparing forwards to backs.

In rugby union, forwards are involved in considerably more contacts per game than backs. The main contributor to this difference is the number of tackles that each positional group makes. On average forwards will make 11-22 tackles per game, whilst the backs make 10-16 per game (Quarrie et al., 2013). Moreover, other contact metrics such as total number of impacts, impacts per minute and severe impacts were extensively higher in the forwards compared to the backs due to the nature of the game and positional task differences (Cunniffe, Proctor, Baker, & Davies, 2009).

Training for Rugby Union

Developing a sports specific strength and conditioning program requires an understanding of the demands placed on athletes during match play. Maximum benefits are obtained when the training stimulus mimics or overloads the physiological performance conditions (Deutsch et al., 1998). Regardless of variance in position, the development and improvement of physical qualities is essential to the progression of rugby players through the various levels of competition. The vital elements of improving physical qualities are, high intensity efforts, increasing muscular strength and power, and expanding aerobic capacity (Duthie et al., 2003).

It has been suggested that optimal training should focus on repeated, brief, high-intensity efforts with short rest intervals to condition players for the demands expected during a rugby union match (Duthie et al., 2003). Along with the ability to produce high intensity efforts, muscular strength and power are essential components that contribute to success in rugby union (Baker & Newton, 2008). Aerobic capacity is also crucial to rugby union performance. Researchers (Deutsch et al., 1998) suggest that aerobic capacity or training for improved aerobic capacity may improve individual recovery ability.

Given that high levels of strength are required during contact situations, forwards should possess greater levels than backs (Gamble, 2004). High levels of strength are also advantageous for improving running velocity, changing directions and producing force in a static context (e.g. scrums and mauls) (Duthie et al., 2003). From a performance perspective, the majority of strength training should focus on the lower extremity, where simultaneous triple extension of the hips, knees and ankles will occur (Gamble, 2004). Moreover, exercise selection should maximize the carry-over of strength and power into sport specific actions rather than training single muscle groups in isolation (Gamble, 2004). Exercise selection is primarily closed kinetic chain multi joint movements, with high force or high velocity contractions required (Hedrick, 2002). The effectiveness and goals of a resistance training program depends on several acute program variables (Bird, Tarpenning, & Marino, 2005). These variables include; (i) repetition maximum (RM) load, (ii) number of sets, (iii) choice of exercise, (iv) order of exercises, and (v) rest periods.

Rugby Union research (Nicholas, 1997) indicates that players must be able to perform a large number of intensive efforts of 5 to 15 seconds duration with less than 40 seconds recovery between each bout. These efforts include activities such as sprinting, tackling and wrestling (Deutsch et al., 1998). The energy contributions during these work periods in Rugby Union are primarily anaerobic in nature (Hedrick, 2002). Moreover, strategies that increase a player's ability to perform repeated bouts of high intensity exercise could significantly enhance Rugby Union performance (Cameron, McLay-Cooke, Brown, Gray, & Fairbairn, 2010). Dupont, Blondel, Lensel, and Berthoin (2002) suggest that intermittent runs at 110% of an athlete's maximal aerobic speed will elicit a stimulus to improve anaerobic threshold and lactate buffering ability. In this study, participants performed six field tests until exhaustion at the same time of the day, separated by at least 48 hours, but all completed within two weeks. They first performed an incremental test and then, in a random order, 4 intermittent exercises and 1 continuous exercise. From a practical point of view, this kind of intermittent exercise could be introduced in a rugby training programme when the purpose is to increase VO_2 max.

Although Rugby Union is an intermittent high-intensity sport, activities are regularly interspersed with periods of low intensity aerobic activity or rest (Cunniffe et al., 2009). The potential benefits of enhanced aerobic capacity are applicable to Rugby Union. Improved aerobic capacity will aid in recovery from high intensity activity and will likely allow players to maintain their work rates/power output towards the end of game compared with those with poorer aerobic capacity (Duthie et al., 2003). In a review by Stone and Kilding (2009), traditional aerobic conditioning involves repeated running intervals at intensities ranging between 85% and 95% of heart rate maximum and lasting up to four minutes, separated with a maximum of three minutes active recovery between intervals. This is evident in preparation of team sport athletes who require a high level of aerobic fitness in order to generate and maintain power output during repeated high intensity efforts and to recover (Stone & Kilding, 2009).

Performance metrics in Rugby Union

The combative nature of match play combined with intermittent high-intensity activity during competition, is synonymous with repeated blunt force trauma, micro damage to skeletal muscle and post exercise soreness (McLellan, Lovell, & Gass, 2010). Physiological variables such as heart rate, blood lactate concentration and fatigue measured to indicate the overall physiological strain associated with competition (Coutts, Reaburn, & Abt, 2003). Whilst fatigue experienced during match play may be manifested in terms of the amount of high-intensity activity performed by players during progressive time periods of the match (Roberts, Trewartha, Higgitt, El-Abd, & Stokes, 2008). Creatine kinase, a biochemical indicator of muscle damage, has been shown to increase significantly pre to post rugby union matches (Smart, Gill, Beaven, Cook, & Blazevich, 2008). Although muscle damage data to some extent is predicted by the number of physical contacts, muscle damage data can also be predicted by high-speed running measures derived from GPS (Jones et al., 2014).

Strength and power are physical attributes that have been shown to be crucial to high level performance in collision sports such as Rugby Union (Hansen, Cronin, Pickering, & Newton, 2011). Although strength and power are not measures of sporting ability, they are believed to represent performance characteristics of playing potential in many sports (Argus, Gill, & Keogh, 2012). Given the complex nature of resistance training prescription for collision sports, training interventions require careful consideration to ensure that training outcomes are achieved (Hansen et al., 2011).

Argus, Gill, Keogh, Hopkins, and Beaven (2009) assessed changes in strength and power professional Rugby Union competition. Thirty two professional Rugby Union athletes from a Super 14 rugby team were assessed for upper-body, lower body strength and power up throughout the competitive season. A small increase in lower body strength was observed over the study period (8.5%) whereas upper-body strength was maintained. Decreases in lower-body power and upper-body power were *small* and *trivial*. Appleby, Newton, and Cormie (2012) assessed the magnitude of upper and lower body strength changes in highly trained professional Rugby Union players after two years of training. This longitudinal investigation tracked maximal strength and body composition over three consecutive years in 20 professional Rugby Union athletes. Maximal strength in the bench press and back squat along with body composition was assessed during preseason resistance training sessions each year. Maximal upper and lower body strength was increased by 6.5-11.5% after two years of training and the magnitude of the improvement was negatively associated with initial strength level. In a study from the same year, Argus et al. (2012), investigated the strength and power characteristics across different levels of play in Rugby Union athletes. 112 participants from four distinct levels of competition (professional, semi-professional, academy and high school 1st XV) tested on two separate occasions to determine individual strength and power. Author's concluded that lower level athletes should strive to attain greater levels of strength and power in an attempt to reach, or to be physically prepared for the next level of competition. Furthermore, the ability to produce high levels of power, rather than strength, may be a better determinate of playing ability between professional and semi-professional athletes.

Part Two - Hypoxic Training

Background

A considerable body of research has investigated the effects of altitude on athletic performance, typically focused on improving endurance-based exercise. Amongst elite athletes and coaches, there is belief that hypoxic training can provide unique sea-level performance enhancements (Pugliese, Serpiello, Millet, & La Torre, 2014). In this context, the same elite athletes and coaches are continuously looking for innovative ways to improve the training stimulus, and moderate altitude training (2000m-3000m) has emerged as a popular ergogenic aid (Girard et al., 2013). As reported by Bärtsch, Saltin, and Dvorak (2008), the change in altitude will have a different impact on players who live and train near sea-level compared with players who live and train at 1500m or higher. There are numerous hypoxic/altitude training methods and protocols (Figure 1). Of these, Intermittent hypoxic training (IHT) has become popular over the past few decades and will be examined closer in Chapter 2 of this thesis. IHT involves residing at sea level and training at altitude (either simulated or natural). The effectiveness of IHT on sea-level performance is debated (Inness, Billaut, & Aughey, 2016) and it is important to note that the physiological responses to natural and simulated altitude may be quite different and controversy exists as to what is the most effective hypoxic exposure (Girard et al., 2013).

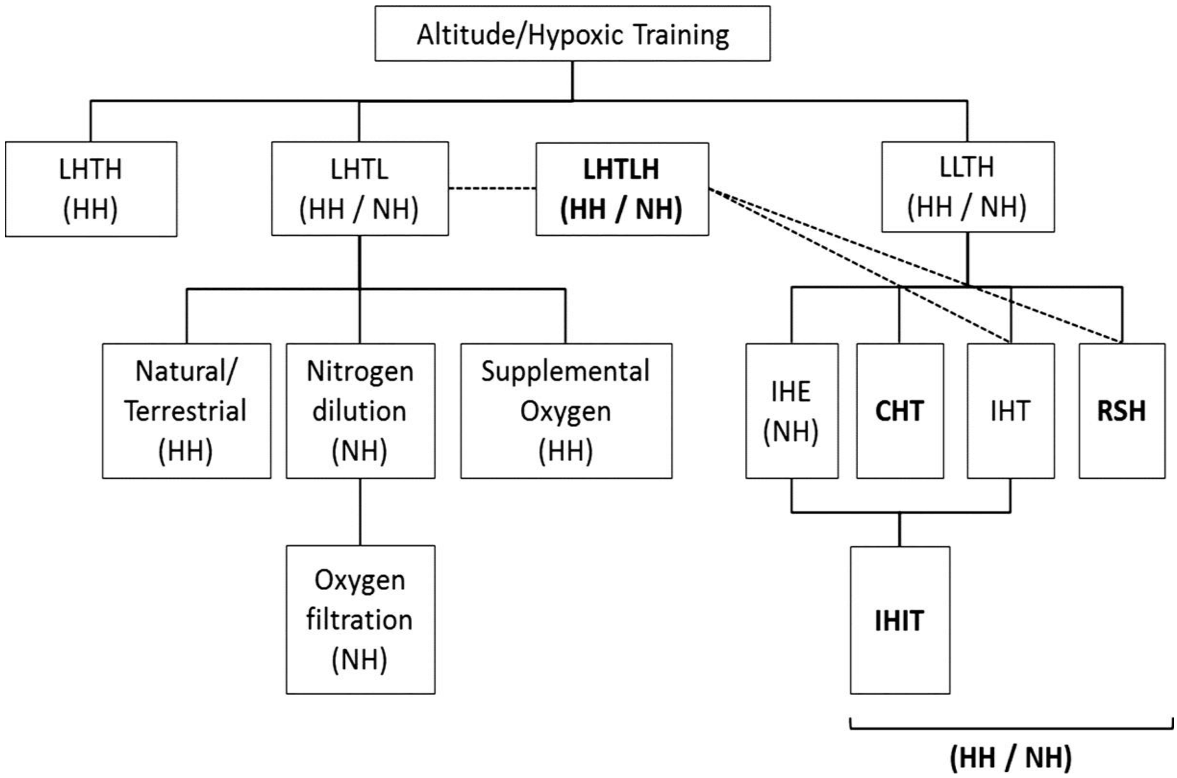

Figure 1 - Panorama of the different hypoxic methods currently available for a range of athletes engaged in endurance and team–sport disciplines (G. Millet, Faiss, Brocherie, & Girard, 2013).

Abbreviations; LHTH, live high–train high; LHTL, live high–train low; LHTLH, live high–train low and high; LLTH, live low–train high; IHE, intermittent hypoxic exposure; CHT, continuous hypoxic training; IHT, interval hypoxic training; RSH, repeated sprint training in hypoxia; IHIT, IHE during interval-training; NH, normobaric hypoxia; HH, hypobaric hypoxia.

Several forms of hypoxic training and/or altitude exposure exist (see Figure 1 above). Although substantial differences exist between these methods of hypoxic training and/or exposure, all have the same goal: to induce an improvement in athletic performance (G. P. Millet, Roels, Schmitt, Woorons, & Richalet, 2010). Before discussing these different methods of altitude training, it is important to establish the definition of different altitude zones as outlined by Bartsch et al, 2008 (Table 2).

Table 2 Definitions of altitude zones (Bärtsch et al., 2008).

0-500m	Near sea level.
500-2000m	Low altitude, minor impairment of aerobic performance becomes detectable.
2000-3000m	Moderate altitude, mountain sickness starts to occur and acclimatization gets increasingly important for performance.
3000-5500m	High altitude, mountain sickness and acclimatization become clinically relevant, performance considerably impaired.
above 5500m	Extreme altitude, prolonged exposure leads to progressive deterioration.

Live High – Train High

The classic "Live High-Train High" (LHTH) method has traditionally been employed, and its efficacy has been shown to be maximal when undertaken above 2000m for at least three to four weeks (Lundby, Millet, Calbet, Bärtsch, & Subudhi, 2012). Athletes train and live at altitude to try and maximize the benefits offered by hypoxic exposure and benefit sea-level performance (Pugliese et al., 2014). The potential benefit of classic altitude training is that altitude acclimatization provides the stimulus for both central and peripheral adaptations, as well as an additional training load compared to sea level (Pugliese et al., 2014). This form of altitude exposure can increase red cell volume (RCV) and at the same time superimpose an additional training stimulus due to tissue hypoxia (Lundby et al., 2012). A high RCV in athletes is well documented and correlates well with overall exercise performance in elite athletes. Whether training in hypoxia actually imposes an additional training stimulus is unknown and it is obvious that this type of training is virtually impossible to blind from participants so questions about methodologies will always exist.

Live High – Train Low

The general theory of live (or sleep) high - train low (LHTL) is to increase performance at sea-level through an altitude induced augmentation of red blood cell mass and thus oxygen carrying capacity (Lundby et al., 2012). Lundby and colleagues have suggested athletes sleep at moderate altitudes to stimulate an increase in RCV therefore avoid the problems associated with reduced VO_2 max and training intensity at altitude by training at sea level.

Live Low – Train High

By using hypoxic conditions for an individual a training session while spending the remainder of the day in normoxia, it is speculated that the oxygen partial pressure is muscle tissue will be further lowered to provide an additional training stimulus (Hamlin & Hellemans, 2007). Recent researchers (Truijens, Toussaint, Dow, & Levine, 2003) observed no performance gain following 5 weeks of high-intensity hypoxic (15.3 O_2) training, refuting the live low - train high (LLTH) hypothesis. In contrast to LHTH and LHTL, research outcomes conclude that LLTH does not increase exercise performance at sea level in endurance athletes any more than simply training at sea level.

Intermittent hypoxia

Altitude simulation involves devices that either decrease the pressure of the inspired air, thus reducing the availability of oxygen to the tissues (nitrogen environmental chamber), or reduce the concentration of oxygen in the inspired air by diluting it with extra nitrogen (Hamlin & Hellemans, 2007). The term “intermittent hypoxia” involves the delivery, at rest, of short bursts of low oxygen air equivalent high altitude (3000 – 6000m) interspersed with recovery periods of normoxic air (Serebrovskaya, 2002).

At present, athletes undertake altitude training due to the performance benefits that are associated with this training stimulus (Nummela & Rusko, 2000; Tyler, Reeve, Hodges, & Cheung, 2016). The majority of this research has investigated the effects on endurance performance (Faiss, Girard, & Millet, 2013). There are few places in the world where altitude training protocol is practical. More recently, the altitude house or environmental chamber was developed to study the LLTH approach. The environmental chamber is a hypoxic environment created by filtering compressed air through a high-polymer membrane (Kon et al., 2014). Once the hypoxic air has been separated, it is sent to the sealed environmental chamber to create a hypoxic environment (Nishimura et al., 2010).

Physiological adaptations to hypoxic training

It is speculated that the partial pressure of oxygen in the muscle tissue will be reduced to provide an additional training stimulus and subsequent increase in training response (Lundby et al., 2012). Exposure to hypoxia through either environmental altitude or simulated hypoxia initiates a series of metabolic and musculocardio-respitory adaptations that influence oxygen transport and utilization (Bailey & Davies, 1997). Some of the possible mechanisms behind increased strength through hypoxic resistance training, whether it is via IHRT or KAATSU/blood flow restriction, include increased type II fibre recruitment (Scott, Slattery, Sculley, & Dascombe, 2014), accumulation of metabolites (Takarada et al., 2000), increases in plasma growth hormone and muscle inflammation (Kon et al., 2014). These adaptations also include an increase in pulmonary ventilation, polycythemia (a rightward shift of the oxygen dissociation curve), an increase in the number of capillaries in peripheral tissues and changes in oxidative enzymes within cells (West, 1984). It is possible that these acute responses, when implemented in a chronic setting, may lead to long-term physiological adaptations (Dufour et al., 2006).

Resistance training has a potent effect on increases in the size and strength of skeletal muscle (Scott, Slattery, Sculley, et al., 2014). When compared with normoxic conditions, resistance training under hypoxic conditions can induce more muscle hypertrophy and muscle strength (Nishimura et al., 2010). It appears that hypoxia may provide an anabolic stimulus by enhancing the metabolic and endocrine response and increase cellular swelling and signaling function following resistance exercise (Scott, Slattery, Sculley, et al., 2014). The same author's also state that increases in muscular strength is likely due to concomitant increases in muscle fibre cross sectional area (CSA) and neural adaptations. Chronic exposure to hypoxia leads to an increase in muscle tissue capillarity and oxidative capacity (Hoppeler et al., 1990). Intermittent hypoxic exposure has been shown to markedly increase erythropoietin release, which probably accounts for the enhancements in hematocrit, red blood cell count, serum heamoglobin and reticulocytes (Hamlin & Hellemans, 2007). The increased "metabolic" stress on skeletal muscle tissue caused by hypoxic training (Hoppeler, Klossner, & Vogt, 2008) is thought to promote muscle adaptations that surpass those triggered by normoxic exercise training. In support of this assumption, it is widely accepted that hypoxic exposure results in an increased renal release of erythropoietin (EPO), which causes a transient increase in red cell volume (Bailey & Davies, 1997). Other potential mechanisms include, but may not be limited to, mitochondrial biogenesis, mitochondrial density and pH regulation (Bailey & Davies, 1997; Faiss et al., 2013; Hoppeler et al., 2008; Rusko, Tikkanen, & Peltonen, 2004).

KAATSU/blood-flow restriction training

Another form of hypoxia is KAATSU/blood-flow restriction training. KAATSU training involves blood flow restriction to the exercising muscle at low intensities (Sato, 2005). Blood flow is restricted via a pressure cuff normally applied to the most proximal portion on either both arms or both legs which provides appropriate superficial pressure (Sato, Yoshitomi, & Abe, 2005). This can cause many perturbations in the muscle, only one of which is hypoxia (Inness, Billaut, Walker, et al., 2016). Restricting blood flow to a muscle can place the tissue in an ischemic state leading to hypoxia (Nakajima et al., 2006). However, there are some practical limitations to the use of KAATSU training. Due to the application of pressure cuffs, typically only isolation exercises are used therefore a large proportion of musculature used is not exposed to hypoxia (Inness, Billaut, Walker, et al., 2016).

Abe, Kawamoto, Yasuda, Midorikawa, and Sato (2005) investigated the effects of short-term KAATSU-resistance training on skeletal muscle size and sprint/jump performance in college athletes. Fifteen male Track and Field college athletes were randomly divided into KAATSU and control groups. The KAATSU group trained twice daily with squat and leg curl exercises (20% of 1 RM, 3 sets of 15 repetitions) for eight consecutive days while both groups participated in the regular sprint/jump sessions. Overall, 30m sprint times improved ($p<0.05$) in the KAATSU group, with significant improvements ($p<0.01$) occurring during the initial acceleration phase (0-10m) but not the other phases (10-20m and 20-30m). None of the jumping performances improved for either the KAATSU or control groups. This data indicated that eight days of KAATSU training improved sprint but not jump performance in collegiate male Track and Field athletes.

Manimmanakorn et al. (2013) used low-load resistance training (20% 1RM) combined with vascular occlusion on neuromuscular function. In a randomized controlled trial, well trained athletes took part in a five-week training of knee flexor/extensor muscles were trained under three conditions. The first used an occlusion pressure cuff of approximately 230 mmHg (KT, n = 10), the second hypoxic air to generate an arterial blood oxygen saturation of ~ 80% (HT, n = 10) and the third had no additional stimulus (CT, n =

10). Before and after training, participants completed the following tests: 3 second maximal voluntary contraction, thirty second maximal voluntary contraction and maximal number of repetitions at 20% 1RM, measured by electromyographic activity and on a seated leg extension. Relative to CT, KT, and HT showed increases in 3 second maximal voluntary contraction and thirty second maximal voluntary contraction tests. The authors theorized that hypoxic conditions created within the muscle during vascular occlusion and hypoxic training may play a key role in these performance enhancements.

Hormonal and inflammatory responses to low-intensity resistance exercise with vascular occlusion were studied by Takarada et al. (2000). Six male athletes performed bilateral knee extension exercise in a seated position with an isotonic leg extension machine, with the proximal end of their thigh compressed at 214 ± 7.7 (SE) mmHg throughout the session of exercise by means of a pressure tourniquet. Concentrations of growth hormone (GH), norepinephrine (NE) and lactate (La), consistently showed marked, transient increases after the exercise with occlusion, whereas they did not change a great deal after the exercise without occlusion (control) done at the same intensity and quantity. Notably, concentration of GH reached a level ~290 times as high as that of the resting level 15 minutes after exercise. The results suggest that extremely light resistance exercise combined with occlusion greatly stimulates the secretion of GH through regional accumulation of metabolites without considerable tissue damage.

Researchers have reported greater hypertrophic and strength responses following IHRT compared to work matched normoxic training. Friedmann et al. (2003) used similar exercise loads (30% 1RM), yet longer inter-set rest periods (60 seconds) and a greater hypoxic stress (FiO_2 = 12%). The authors observed no additive benefits of IHRT. While conflicting, this research demonstrates that when using low loads, duration of inter-set rest periods and the level of hypoxia can affect the adaptive responses.

Hypoxic resistance training and performance

Athletic exposure to altitude has been shown to have different effects depending on the duration and intensity of the stimulus. To our knowledge, eight published studies have investigated and assessed the effectiveness of IHRT for increased muscle strength when compared to the equivalent training under normoxic conditions. These studies are summarised in Table 1.

In the study by Inness, Billaut, Walker, et al. (2016), twenty resistance trained males were either assigned a IHRT (FiO_2 0.14) or a placebo (FiO_2 0.20) group, (n = 10 per group) for 20 resistance training sessions over seven weeks. Participants were tested for 1RM squat strength, 20m sprint, body composition and countermovement jump before and after the training intervention. The authors concluded that there was greater change in the IHRT group for 1RM squat strength. Participants improved both absolute strength (pre; 121.4 ±22.1 kg, post; 148.4±32.7 kg) and relative strength (pre; 1.46±0.19 $kg.bm^{-1}$, post 1.76±0.26 $kg.bm^{-1}$) 1RM squat strength. As reported by the authors, these results are likely greater changes than the placebo group. Only the IHRT group increased countermovement jump peak power at following the training intervention. However, no clear difference between groups was found for speed or body composition.

Kon et al. (2014) investigated the effects of systemic hypoxia on muscular adaptations to resistance training exercise. Sixteen healthy male subjects were randomly assigned to either a normoxic resistance training group (n = 7) or a hypoxic (14.4% oxygen) resistance training group (n = 9) and performed eight weeks of resistance training. The resistance exercise consisted of two consecutive exercises, free weight bench press and bi-lateral leg press, each with ten repetitions for five sets. The researchers concluded that resistance training under hypoxic conditions led to greater increases in muscular endurance, however, although both groups 1RM strength increased, but no significant differences between groups were observed.

Nishimura et al. (2010) demonstrated that resistance training under hypoxic conditions improved muscle strength and increased muscle hypertrophy at a faster rate than under normoxic conditions, thus representing a novel training method. Fourteen male university students were randomly assigned to either a hypoxia (n = 7) or a normoxia group (n = 7). Each group preformed four sets of ten reps of elbow extension and flexion, twice a week for six weeks. Muscle hypertrophy was significantly greater for the hypoxic exercise group compared to the normoxic exercise group. Muscle strength was significantly increased early (by week 3) in the hypoxic exercise group but the normoxic exercise group. Ho, Huang, Chien, Chen, and Liu (2014) used similar exercise loads (70% 1RM or 10RM) and similar levels of hypoxia (FiO_2 = 14.4-15%) in conjunction with longer inter-set rest periods (90-120 seconds) and found no additive hypertrophic or strength benefits using IHRT.

Furthermore, a study by Kurobe et al. (2015) employed moderate-load exercise (elbow extension at a workload of a 10RM) and brief inter-set rest (60 seconds) but a high level of hypoxia (FiO_2 = 12.7%). Three sets of elbow extensions with unilateral arm were performed for 3 days per week for 8 weeks. Compared to normoxic training, the enhanced muscle thickness in triceps brachii in the trained arm was also significantly greater in the hypoxic group than in the normoxic group. The hypoxic group also displayed significantly greater hypertrophic, but not strength adaptations, following IHRT. These findings suggest that hypoxic resistance training elicits more muscle hypertrophy but the greater hypertrophy did not necessarily contribute a greater gain of muscle strength.

Conclusion

Given the physical demands and competitiveness of Rugby Union, advances in training strategies have emerged causing practitioners to look at alternative ways to increase the training stimulus. While hypoxia is commonly used in endurance athletes to improve adaptations and performance, there is limited research on its effectiveness in a resistance training setting in professional athletes.

Further research is needed to understand the effect hypoxia on strength trained individuals and athletic performance. Current literature demonstrates positive findings on hypertrophy and absolute and relative strength improvements. Given the disparate findings on IHRT, and the range of methodologies and protocols used in the literature, further research is required to determine the efficacy of such a technique. Currently limited literature exists on the use of hypoxia in Rugby Union athletes. Research on the topic is of great importance due to anecdotal claims that the hypoxia is already being used by professional athletes in Rugby Union despite little being known about its benefits or limitations.

Table 2 - Summary of studies investigating intermittent hypoxic resistance training on athletic performance.

Author	Hypoxic stimulus	Altitude (m)	Exposure Time (days)	Control Group	No. of Participants	Sport	Training Status	Performance Test	Effect Size	P-value
Inness, Billaut, Walker, et al. (2016)	IHRT Hypoxic simulator	3100m 4 weeks 3400m 3 weeks	20 sessions over 7 weeks	Yes - normoxia	20	Not stated	Trained	1RM back squat, CMJ 20m sprint	↑1.22, *large* ↑0.52, *moderate* ↑0.13, *trivial*	NR NR NR
Nishimura et al. (2010)	IHRT Environmental Chamber	2000m	12 sessions over 6 weeks	Yes - normoxia	14	Not stated	Untrained	Elbow extension Elbow flexion	NR NR	<0.01 <0.01
Kon et al. (2014)	IHRT Environmental Chamber	3000m	16 sessions over 8 weeks	Yes - normoxia	16	Not stated	Untrained	Bench press Bilateral leg press	NR NR	<0.01 <0.01
Friedmann et al. (2003)	IHRT Environmental Chamber	4500m	12 sessions over 4 weeks	Yes - normoxia	19	Not stated	Untrained	Isokinetic one leg knee extension	↑0.25, *small*	NR
Kurobe et al. (2015)	IHRT Environmental Chamber	4000m	24 sessions over 8 weeks	Yes - normoxia	13	Not stated	Untrained	Elbow extension	NR	<0.05
Ho, Huang, et al. (2014)	IHRT Environmental Chamber	2500m	18 sessions over 6 weeks	Yes - normoxia	10	Not stated	Untrained / Recreational	Back squat	↑1.21, *large*	>0.05
Abe et al. (2005)	Controlled occlusion		16 sessions over 8 days	Yes	15	Track & Field	Trained	30m sprint Standing jump Leg press 1RM	↑0.57, *moderate* ↑0.09, *trivial* ↑0.28, *small*	<0.05 >0.05 <0.01
Manimmanakorn et al. (2013)	Controlled occlusion		15 sessions over 5 weeks	No	30	Netball	Trained	Vertical jump 10m sprint	↑0.46, *small* ↑0.60, *moderate*	NR NR

Abbreviations:IHRT: intermittent hypoxic resistance training, m: meters, 1RM: 1 repetition maximum, CMJ: countermovement jump, NR: not reported. Effect size thresholds of <0.2, 0.2, 0.5, 0.8 for *trivial, small, moderate and large*, respectively (Cohen, 1988)

Chapter Two:

The effect of resistance training in a hypoxic chamber on physical performance in elite rugby athletes

This chapter appears in the same format that was required by the journal *High Altitude Medicine and Biology* where it has been published.

Abstract

Limited research suggests that muscle adaptations may be enhanced through resistance training in a hypoxic environment. Seventeen professional rugby union athletes (age [mean ± SD], 24 ± 3 years; body mass, 98.7 ± 12.8 kg, height; 188.9 ± 7.9 cm), performed 12 resistance training sessions over a three week period. Participants were randomly divided into two groups: HYP (n=8) where resistance training sessions were performed in an environmental chamber with O_2 concentration maintained at ~14.4% (~3000m simulated altitude), or CON (n=9) identical resistance training sessions were performed without the simulated altitude (O_2 = 20.9%, at sea level). Pre and post training intervention, tests included measures of strength, power, endurance, speed and body composition. Two-way interactions between treatment and time for any of the measured variables were not significant ($p > 0.05$). *Small* positive effect sizes for HYP were found for bench press ($d = 0.24$), weighted chin-up ($d = 0.23$) and bronco endurance tests ($d = -0.21$). Resistance training in a hypoxic environmental chamber may lead to *small* improvements in upper body strength and endurance compared to the same training performed at sea-level. These findings are somewhat novel, given the short timeframe of the study and the elite population sampled.

Keywords: hypoxia, altitude, intermittent hypoxic resistance training (IHRT), strength and conditioning.

Introduction

Resistance training plays an integral part in the physical preparation of rugby athletes (Inness, Billaut, Walker, et al., 2016). The development of strength and power is important for rugby athletes who are required to perform numerous high speed runs, sprints, acceleration/decelerations and collision-based activities like tackling, static holds, scrums, rucks and mauls (Tavares, Smith, & Driller, 2017). Strength development involves the coordinated functioning of a number of processes with the ability to produce maximal force attributed to both neural and muscular components (Bird et al., 2005). Moreover, strength improvements are likely due to concomitant increases in muscle cross sectional area (CSA) and neural adaptations (Bird et al., 2005). Subsequent adaptations to resistance training are highly dependent on the interplay between loads and volume, with the optimal range of training stimuli being a fine balance to ensure strength and power gains without overloading the athletes (Bird et al., 2005). Because of this, practitioners working with rugby athletes are often in search of ways to add stress to the training environment, without adding unnecessary load or volume.

Stress may be added to the resistance training setting by manipulation of environmental factors such as heat, humidity and simulated altitude, or hypoxia, without adjusting the training volume or load (Scott, Slattery, Sculley, et al., 2014). The positive effects of resistance training under local or systemic hypoxia are becoming more evident in the research (Ho, Huang, et al., 2014; Inness, Billaut, Walker, et al., 2016; Manimmanakorn, Hamlin, Ross, Taylor, & Manimmanakorn, 2012; Nishimura et al., 2010). By performing training under hypoxic conditions, it is speculated that the partial pressure of oxygen in the muscle tissue will be reduced to provide an additional training stimulus and subsequent increase in training response (Lundby et al., 2012). While the use of environmental chambers during resistance training is limited in the research literature, other strategies used during resistance training that may induce similar physiological mechanisms include the use of blood flow restriction (BFR) training, whereby a pressure cuff is applied proximally to a limb to partially limit blood flow to working muscles (Scott, Slattery, Sculley, et al., 2014). Some of the possible mechanisms behind increased strength through hypoxic resistance training, whether it is via BFR or intermittent hypoxic resistance training (IHRT), include increased metabolic stress accentuated by an overall reliance on non-aerobic metabolism and fatigue , reduced oxygenation can enhance epigenetic changes via the transcription of angiogenesis-related genes (Larkin et al., 2012) increased type II fibre recruitment (Scott, Slattery, Sculley, et al., 2014), accumulation of metabolites (Takarada et al., 2000), concomitant increase in the rate of PCr hydrolysis and intracellular acidosis (Ramos-Campo et al., 2017) and increases in plasma growth hormone and muscle inflammation (Kon et al., 2014). It is possible that these acute responses, when implemented in a chronic setting, may lead to long-term physiological adaptations.

The research on IHRT has resulted in conflicting findings on its effectiveness for increasing maximal strength in athletes (Scott, Slattery, & Dascombe, 2014). Manimmanakorn et al. (2012) investigated the effects of low-load resistance training on muscle function and performance in 30 netball athletes while breathing hypoxic air (equivalent to 2000-4500m altitude). Athletes took part in 5 weeks training of knee flexor and extensor muscles at an intensity of 20% of 1RM. The IHRT group showed greater hypertrophy and strength improvements than the control group. More recently, Kon et al. (2014) studied 16 recreationally trained participants split into an experimental and control group, performing 2 sessions a week for 8 weeks. The hypoxic group was exposed to normobaric hypoxic conditions (~3000 meters) in which they performed two consecutive exercises (free weight bench press and bi-lateral leg press using a weight-stack machine). Both groups performed 5 sets of 10 reps at 70% of 1RM on each exercise. The authors found no additive hypertrophic or strength benefits for IHRT. Furthermore, Ho, Kuo, Liu, Dong, and Tung (2014), investigated whether short-term moderate-intensity resistance training performed under systemic hypoxia will lead to greater muscular strength and hypertrophy. Eighteen untrained men performed 6 weeks of squat exercise under normobaric conditions. In both groups, participants performed 3 sets of back squats at 10RM with 2 minutes rest between sets. The findings from this study suggest that short-term resistance training performed under normobaric hypoxia has no additive beneficial effect on muscular performance.

Given the disparate findings on IHRT, and the range of methodologies and protocols used in the literature, further research is required to determine the efficacy of such a technique. Therefore, the aim of the current study was to investigate the effect of resistance training for 3-weeks in hypoxia (via a simulated altitude chamber) for developing measures of maximal strength, power, speed and endurance in professional rugby athletes.

Materials and Methods

Participants

Seventeen elite, professional rugby union athletes (age [mean ± SD], 24 ± 3 years; body mass, 98.7 ± 12.8 kg, height; 188.9 ± 7.9 cm) were split into two groups: HYP (n = 9) and CON (n = 8). Participants were first divided into positional groups (forwards and backs) and were then randomly allocated with an even distribution of each in both groups. All athletes were from the same rugby union squad, which played in New Zealand's top provincial competition. The study took place during the pre-season phase of competition, which included 4 weeks of training prior to this study. All athletes volunteered to take part in the present study. Written informed consent was obtained from each participant, and ethical approval was obtained from the Human Research Ethics Committee of the Institution. Initially, the study included 19 participants, however, two were withdrawn from the study due to injuries sustained during activities unrelated to the study.

Study design

The present study implemented a randomized, controlled, parallel-group design performed over five weeks. This included a week of pre-testing, 3-weeks of intervention training (4 sessions per week) and a week of post-testing. In addition, all participants were involved in the same team training activity outside their resistance training sessions, where training loads were monitored to ensure there were no differences between groups. Both the experimental (HYP) and control (CON) groups performed exactly the same resistance training load, volume and intensity over the three week intervention period (see Table 1), with the only difference between groups being the training environment:

HYP – 12 resistance training sessions were performed in an environmental chamber, where O_2 concentration was maintained at ~14.4% (equivalent to ~3000 meters simulated altitude).

CON – 12 resistance training sessions were performed using the same equipment, but without the simulated altitude (O_2 = 20.9%, at sea level).

All the participants reside at sea level (O_2 = 20.9%, at sea level) and had no previous exposure to altitude in the past 6 months.

To investigate any differences in perceived intensity between groups, the level of perceived exertion was assessed at the completion of each training session using the Borg 6-20 RPE scale (Borg, 1982).

Simulated altitude (hypoxia)

The altitude chamber (Synergy Fitness, Queensland, Australia) consisted of a hypoxic generator, a compressor and an air-tight room (width x length x height: 4900 x 4600 x 2300 cm). The hypoxic environment was created by filtering compressed ambient air through a high-polymer membrane that was sent to the air-tight chamber by the compressor. The initial training session was set to 15.5% O_2 (~2800 meters equivalent), with a decrease in O_2 to 14.4% (~3000 meters equivalent) for the remaining 11 training sessions. During each of the training sessions in the HYP group, SpO_2 was monitored at 0, 15 and 30 minutes using a PureSAT GO_2 pulse oximeter (Plymouth, Minnesota, USA) placed on the middle finger of the dominant hand. SpO_2 measurement was used as a safety measure. Athletes were to be removed from the chamber if their SpO_2 readings dropped below 80%, fortunately, this did not occur.

Testing Procedures

Testing was carried out over one week under controlled environmental conditions (21 ± 1°C and 56.8 ± 8.5% RH at sea-level). All participants were familiar with the testing procedures and protocols, as they had been performing these as part of their regular physical testing routines. The one repetition maximum (1RM) lifts (bench press, back squat and weighted chin-up) and body composition measures (sum of 8 skinfolds and body mass) were performed on day one, the bodyweight counter movement jump (CMJ) and 10 meter sprint on day four, and the bronco fitness test on day five of the first week (Table 1). All physical performance tests were preceded by a standardized warm-up specific to the test. These warm-ups included sub maximal lifting reps in preparation to lift a 1RM, sub maximal and maximal countermovement jumps and a self-selected sprint preparation.

1RM Testing

The monitoring of maximum strength was obtained from 1RM testing of the back squat, bench press and weighted chin-up exercises pre and post the training intervention. The determination of 1RM for these exercises was conducted according to the recent research (Baker & Nance, 1999; Haff & Triplett, 2015). Squat depth was visually assessed by the same researcher for all 1RM load attempts, with the athlete required to descend to a depth to which the femur was approximately parallel to the floor. The order of the 1RM exercises was: back squat, bench press and weighted chin-up; and was maintained for the two testing sessions.

Power Testing

A countermovement jump (CMJ) was used to test lower-body power. Athletes started with both feet on the floor, placed a shoulder width apart and with both hands on a wooden bar placed across the upper trapezius. Athletes were instructed to perform 5 cyclic vertical CMJ's, aiming for maximum height with each jump (Cormack, Newton, McGuigan, & Doyle, 2008). The best CMJ measured by peak velocity was used for subsequent analysis. CMJ performance was measured using a linear position transducer (Gymaware, Kinetic Performance Technology, Canberra, Australia) at a sampling frequency of 50 Hz. The linear position transducer was attached to the bar laterally to the athletes left hand and to the floor directly beneath.

Speed Testing

Speed was tested over 10m from a standing start. Participants performed three trials of maximum effort, with the fastest time being recorded for subsequent analysis. Athletes were instructed to stand 50 cm behind the first timing gate before starting when they were ready. Sprint speed was measured using single beam infrared timing lights set to a height of 0.73 m (TC-Timing System, Brower, Draper, Utah, United States of America). The intra-trial reliability of the above procedure has been established at r = 0.86 for the 10 m trained athletes (Baker & Nance, 1999).

Endurance Testing

In order to measure the athlete's aerobic fitness, a bronco test was performed pre and post training intervention. The bronco test is widely used in the rugby environment and consists of running 1200 meters in a shuttle-type fashion. Cones were placed at the 0 m, 20 m, 40 m and 60 m lines. Athletes were asked to run from 0 to 20 m, return to the 0 m line, run again to the 40 m line and return to the 0 m line, then run again to the 60 m line and return to the 0 m line. Completion of the 20-40-60 m shuttles was considered one repetition, with athletes completing 5 repetitions as quickly as possible. Hand-held stop watches were used by trained time-keepers to record the bronco finishing times.. As mentioned by Berthon et al. (1997), a 5 minute field test is easy to apply and a practical test for this setting.

Body Composition

Skinfold thickness was measured on the right side of the body with Harpenden calipers to the nearest 0.5 mm at eight sites (biceps, triceps, subscapular, iliac crest, suprailiac, abdomen, thigh and calf) by one investigator using standardized techniques (Moreno, Rodríguez, Guillén, & Rabanaque, 2002). Sum of skinfold thickness at these eight sites was used for analysis.

Table 3 – Testing and training schedule for both HYP and CON groups for the duration of the study. All exercises are represented as repetitions x sets.

Week	Monday	Tuesday	Thursday	Friday
1 **Pre Test**	Back squat 1RM Bench press 1RM Weighted chin-up 1RM Skinfolds & Body mass		Bodyweight CMJ 10 meter sprint	Bronco fitness test
2	Bi-Lateral Strength: Back squat (4 x 3) DL calf raise (4 x 12) 3 minutes rest after each super-set	Horizontal Strength: Bench press (4 x 5) Bent over row (4 x 10) 3 minutes rest after each super-set	Vertical Strength: Weighted chin-up (4 x 5) Seated BB shoulder press (4 x 10) 3 minutes rest after each super-set	Strength & Speed: BB high pull (4 x 3) KB single leg Romanian deadlift (4 x 6) 3 minutes rest after each super-set
3	Bi-Lateral Strength: Back squat (3 x 2, 2 x 1) DL calf raise (4 x 12) 3 minutes rest after each super-set	Horizontal Strength: Bench press (4 x 4) Bent over row (4 x 8) 3 minutes rest after each super-set	Vertical Strength: Weighted chin-up (4 x 4) Seated BB shoulder press (4 x 8) 3 minutes rest after each super-set	Strength & Speed: BB high pull (4 x 3) KB single leg Romanian deadlift (4 x 6) 3 minutes rest after each super-set
4	Bi-Lateral Strength: Back squat (2 x 2, 3 x 1) DL calf raise (4 x 12) 3 minutes rest after each super-set	Horizontal Strength: Bench press (4 x 3) Bent over row (4 x 6) 3 minutes rest after each super-set	Vertical Strength: Weighted chin-up (4 x 4) Seated BB shoulder press (4 x 6) 3 minutes rest after each super-set	Strength & Speed: BB high pull (4 x 3) KB single leg Romanian deadlift (4 x 6) 3 minutes rest after each super-set
5 **Post Test**	Back squat 1RM Bench press 1RM Weighted chin-up 1RM Skinfolds & Body mass		Bodyweight CMJ 10 meter sprint	Bronco fitness test

FB = full body; 1RM = one repetition maximum; CMJ = counter movement jump; DL = double leg; KB = kettle bell; BB = barbell;

Statistical analysis

Statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL). A two-way repeated measures ANOVA was performed to determine the effect of different treatments (HYP or CON) over time (pre/post) on all measured variables, with a Bonferroni adjustment if significant main effects were present. Analysis of the studentized residuals was verified visually with histograms and also by the Shapiro-Wilk test of normality. A Student's paired t-test was used to determine pre to post differences for each measure and an independent t-test was used between groups for pre test values. Descriptive statistics are shown as means ± standard deviations unless stated otherwise. Standardized changes in the mean of each measure were used to assess magnitudes of effects and were calculated using Cohen's *d* and interpreted using thresholds of 0.2, 0.5, 0.8 for *small, moderate and large*, respectively (Cohen, 1988). An effect size of ±0.2 was considered the smallest worthwhile effect with an effect size of < 0.2 considered to be *trivial*. The effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and negative effects (Batterham & Hopkins, 2006). Statistical significance was set at $p < 0.05$ for all analyses.

Results

There were no statistically significant differences between groups for pre-test values for any of the measured variables ($p > 0.05$), except for bench press, which was significantly higher in the HYP group.

The average duration for each of the 12 sessions in the HYP group was 34 ± 2 mins (total altitude exposure over 3 weeks = ~7 hours) and the mean simulated altitude was 3098 ± 68m.

There were no significant differences between groups for mean RPE during the resistance training sessions over the intervention period (14.2 ± 0.5 and 14.1 ± 0.4 for HYP and CON, respectively).

There were no statistically significant two-way interactions between treatment and time for any of the measured variables ($p > 0.05$). However, there were *small* effect sizes in favour of the HYP group compared to CON for the bench press ($d = 0.24$), weighted chin-up($d = 0.23$) and bronco tests ($d = -0.21$) (Figure 1).

Significant improvements were seen pre to post testing in the HYP group for bench press, back squat and weighted chin-up, and for back squat in the CON group ($p < 0.05$, Table 2).

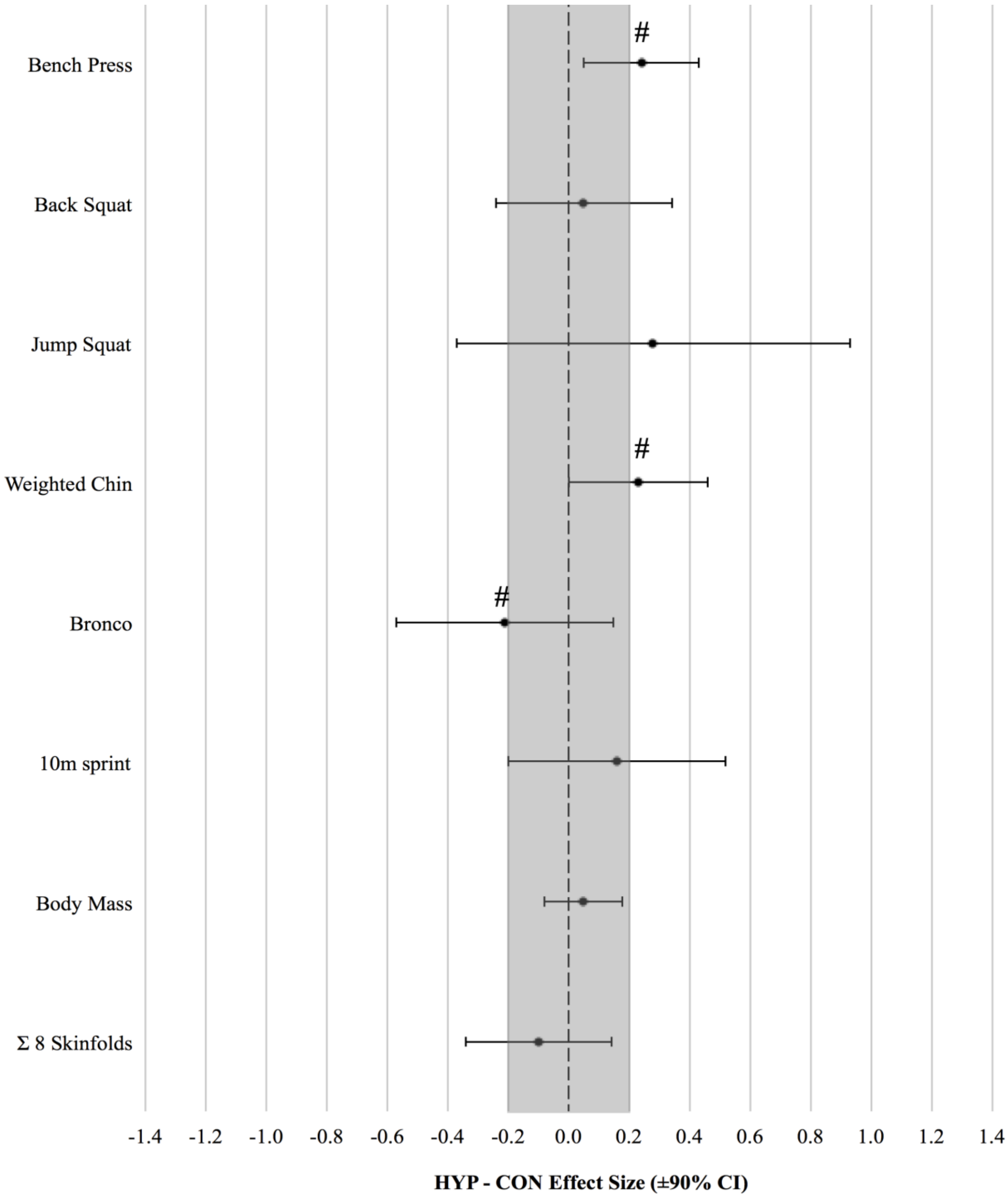

Figure 2 – Effect sizes for measured variables between HYP – CON groups. Error bars represent 90% confidence intervals (±90% CI), with the shaded area representing a *small* effect (±0.2) between groups. Where 90% confidence intervals overlap *small* positive and negative effects, the result was deemed *unclear*. # = *small* effect between groups.

Table 4 - Pre and post measures (mean ± SD) for HYP and CON groups and p-values and effect sizes for the comparison of change between groups. # Represents significant difference between pre and post ($p < 0.05$).

	HYP (mean ± SD)		CON (mean ± SD)		ΔHYP – ΔCON (mean ±90%CI) Effect size
	Pre	Post	Pre	Post	
Bench Press (kg)	137 ± 14	145 ± 14#	115 ± 18	118 ± 17	5 ±4 *Small*
Back Squat (kg)	167 ± 28	178 ± 27#	168 ± 20	177 ± 20#	1 ±8 *Unclear*
Weighted Chin-Up (kg)	145 ± 10	151 ± 9#	130 ± 18	133 ± 17	4 ±4 *Small*
Jump Squat ($m.s^{-1}$)	3.61 ± 0.39	3.82 ± 0.44	3.63 ± 0.33	3.73 ± 0.31	0.11 ±0.25 *Unclear*
Bronco (seconds)	302 ± 36	297 ± 34	299 ± 16	300 ± 19	-6 ±9 *Small*
10m sprint (s)	1.75 ± 0.12	1.74 ± 0.12	1.75 ± 0.06	1.73 ± 0.06	0.02 ±0.03 *Trivial*
Body Mass (kg)	100 ± 14	101 ± 13	95 ± 11	95 ± 10	1 ±2 *Trivial*
Σ 8 Skinfolds (mm)	93 ± 38	89 ± 34	85 ± 21	85 ± 18	-3 ±8 *Trivial*

Discussion

Resistance training in a hypoxic chamber may lead to *small* changes in upper body strength (bench press and weighted chin-up) and endurance (bronco test) compared to the same training at sea-level in professional rugby athletes. The hypoxic group in the current study also demonstrated significant ($p < 0.05$) increases between pre and post tests for bench press, back squat and weighted chin-up, while the control group only showed significant improvements pre to post training for the back squat. Considering the participants were professional-level, strength-trained athletes, the *small* trends towards improved performance highlighted after just three weeks of hypoxic resistance training are somewhat surprising and warrant future research.

Our results would suggest that resistance training in hypoxia may show trends towards improving physical performance, particularly for improving upper-body strength. The current study is the first to investigate the use of high-load resistance training combined with hypoxia, in elite athletes. Our study implemented a training program that consisted of different lifts at 85-92.5% of 1RM, whereas the majority of published IHRT studies have used low to moderate loads of 20-75% of 1RM. Given the current study population included a high level of resistance trained athletes, it is unlikely that the strength increases were due to neural adaptations alone (Bird et al., 2005). Although no observable changes to body mass were found with increased 1RM, it could be that hypoxia mediated hypertrophic changes were too small to be quantified without MRI. However, these findings are consistent with the results of the Inness, Billaut, Walker, et al. (2016) study, where changes in 1RM performance were evident, also without changes in body mass. This change in strength despite a lack of change in body mass is an important finding, as many athletes, including team-sport athletes with high running demands in their sport, athletes competing in weight classes, and many endurance athletes want to increase strength without an increase in body mass.

Previous research by Nishimura et al. (2010) using moderate loads (70% 1RM) combined with moderate-level hypoxia (FiO_2 = 16%) demonstrated enhanced hypertrophic and strength responses following IHRT compared to the equivalent training in normoxia in untrained participants. The groups performed resistance training twice a week for 6 consecutive weeks (totaling 12 sessions), with the mean duration of each training session lasting ~13 minutes. The authors found that 1RM had significantly increased in the hypoxic group by week 6, similarly to the results found in the current study. Furthermore, research by Inness, Billaut, Walker, et al. (2016) employed heavy-load exercises (3-6RM) at higher levels of hypoxia ($Fi0_2$ = 14.5% - 14.1% ; 3100 m – 3400 m equivalent altitude). Participants completed 7 weeks of heavy resistance training three times per week, with sessions performed on non-consecutive days. During the training sessions, all participants wore a face-mask connected to a hypoxic simulator. Authors noted greater improvements in relative and absolute strength compared to a placebo intervention, but no clear differences in speed or body composition. The results of the present study are in agreement with these reported findings.

Historically, hypoxic research has investigated changes in aerobic responses to exercise (Hamlin, Marshall, Hellemans, Ainslie, & Anglem, 2010). The results of the present study demonstrated that IHRT showed *small* benefits to aerobic performance capacity and changes observed in the bronco test are similar to those found in previous literature (Dufour et al., 2006; Levine & Stray-Gundersen, 2005; Morton & Cable, 2005). In the aforementioned research, hypoxic exposure elicited significant improvements of maximal and submaximal running velocities and VO_2 max. In research by Levine and Stray-Gundersen (2005), an increase in endurance running performance was attributed to increases in erythrocyte volume, red cell mass and VO_2 max following ~3 weeks of altitude exposure. The increased “metabolic” stress on skeletal muscle tissue caused by hypoxic training (Hoppeler et al., 2008) is thought to promote muscle adaptations that surpass those triggered by normoxic exercise training. In support of this assumption, it is widely accepted that hypoxic exposure results in an increased renal release of erythropoietin (EPO), which causes a transient increase in red cell volume (Bailey & Davies, 1997). Other potential mechanisms include, but may not be limited to, mitochondrial biogenesis, mitochondrial density and pH regulation (Bailey & Davies, 1997; Faiss et al., 2013; Hoppeler et al., 2008; Rusko et al., 2004). It is plausible that the simulated altitude exposure alone used in the current study may have led to aerobic adaptations and improved performance highlighted in the bronco endurance test.

A limitation of the current study was the lack of placebo-control. As with many hypoxic studies, it is somewhat difficult to control for the placebo effect, therefore, psychological benefits associated with the intervention cannot be discounted. Future research should examine the psychological belief in IHRT prior to the study, to help determine whether or not the prior belief in the efficacy of this training may have had an influence on the performance results. Future research should also incorporate longer training interventions, different levels of hypoxia and physiological measures to determine the mechanistic changes associated with any performance benefits (e.g. blood, hormonal and muscle cell adaptations).

In conclusion, resistance training in a hypoxic environment, via simulated altitude over a 3-week period may lead to *small* improvements in upper body strength and endurance compared to the same training performed at sea-level in professional rugby athletes. The current study is the first to highlight such findings in an elite, strength-trained population and further research incorporating longer training periods and more mechanistic measures are clearly warranted.

Chapter Three:

Conclusion, Practical Applications & Future Research

Conclusion

The study included in this thesis (Chapter Two) was designed to investigate the effect of resistance training in a hypoxic chamber on physical performance in elite Rugby Union athletes. The research found that resistance training in a hypoxic environment via simulated altitude over a 3-week period lead to *small* improvements in endurance and upper body strength compared to the same training performed at sea-level in professional rugby athletes. This study is the first to highlight such findings in an elite, strength-trained population and further research incorporating longer training periods and more mechanistic measures are clearly warranted. Whilst the research demonstrated alterations to physical parameters, further research is needed to confirm the exact mechanisms behind these alterations. In recent years, some researchers have speculated that combining systemic hypoxia through the use of altitude tents or rooms with resistance training may provide additive beneficial effects on muscular strength and body composition. Their speculations were based on the beneficial effects observed from combining occlusion training or KAATSU training with resistance training. Although further investigation is needed, heavy resistance training under hypoxia appears to offer a practical and effective method of increasing strength and inducing muscle hypertrophy.

Practical applications

The evidence from this reaserach does support the use of strength training in a hypoxic environment. These findings provide important information for training prescription and assisting with the development of physical qualtities in elite rugby athletes. In practical terms, athletes wanting to increase strength without increasing muscle mass are advised to undertake acute duration (3 weeks) heavy (85-92.5% 1RM) resistance training in systemic hypoxia.

Future research

This research should act as a reference for future work in the area. The following recommendations are made for future research:

- Individual responses in our research varied; therefore further research should look to investigate whether training status has an impact on results and attempt to understand if responders and non-responders exist.
- Future research should aim to scrutinize whether there may be a dose-response relationship with altitude exposure and hypertrophic or strength improvements, and determine the specific mechanisms that may enhance these physical qualities. Further studies are needed for clarification regarding the effects of intensity and hypoxia severity on hypoxia-induced physiological benefits.
- Physiological measures to determine the mechanistic changes associated with any performance benefits (e.g. growth hormone and testosterone responses, cortisol and muscle cell adaptations). Resistance training under systemic hypoxia has been reported to have greater hormonal responses than under normoxic conditions. The exact mechanisms are still to be confirmed.
- Future research should ensure a longer intervention with multiple mechanistic measures at different time points e.g. pre, 3 weeks, 6 weeks and post.

Limitations

A limitation of the current study was the lack of a placebo condition and biological markers used to detect hormonal responses to training. The psychological advantage that may be associated with training inside the environmental chamber can not be discounted. However, the experimental intervention in this case is difficult to provide a placebo condition for given it is quite noticeable when athletes are in a reduced O_2 environment. Moreover, the length of the training intervention is also a limitation. Therefore, it may have been useful to extend the intervention time frame to >4 weeks. The small sample size may have influenced the lack of significance between conditions, and may not have been a true representation of the population of interest.

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Appendices

Appendix 1 - Ethics approval

The University of Waikato
Private Bag 3105
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Human Research Ethics Committee & Human Research Ethics Committee (Health)
Julie Barbour
Telephone: +64 7 837 9336
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THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

28th July 2017

Stacy Sims

Dear Stacy,

HREC(Health)#09 Effects of heat, humidity and simulated altitude exposure on physiological performance during exercise and resistance training.

We understand that you would like to add Student Researchers/Research Assistances to your project. They may use project data for the purpose of writing Masters Theses. You have amended your application form and documents for participants to reflect these changes, and your request is now approved.

Please contact the committee if you wish to make further changes to your project as it unfolds, quoting your application number HREC(Health)2016#09), with your future correspondence. Any minor changes or additions to the approved research activities can be handled outside the monthly application cycle.

Regards,

Julie Barbour PhD
Chairperson
University of Waikato Human Research Ethics Committee (Health)

Appendix 2 - Research consent form

Research Consent form

Project Title: The effect of resistance training in a hypoxic chamber on physical performance in elite rugby athletes.

Principal Researchers: Brad Mayo, Cory Miles, Dr. Stacy Sims, Dr. Matt Driller.

This is to certify that I, hereby agree to participate as a volunteer in a scientific investigation as an authorised part of the research program of the Waikato University School of Human Development and Movement Studies under the supervision of Dr. Matt Driller. .

The investigation and my part in the investigation have been defined and fully explained to me by and I understand the explanation. A copy of the procedures of this investigation and a description of any risks and discomforts has been provided to me and has been discussed in detail with me.

- I have been given an opportunity to ask whatever questions I may have had and all such questions and inquires have been answered to my satisfaction.

- I understand that I am free to withdraw consent and to discontinue participation in the project or activity at any time, without disadvantage to myself.

- I understand that I am free to withdraw my data up until the point of recording without disadvantage to myself.

- I understand that any data will remain anonymous with regard to my identity through a coding system. The data will be made publishable, so every effort will be made to ensure confidentiality, however this cannot be guaranteed.

- I certify to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participation in this investigation.

- I am participating in this project of my (his/her) own free will and I have not been coerced in any way to participate.

Signature of Subject: ____
Date: ____/____/____

I, the undersigned, was present when the study was explained to the subject/s in detail and to the best of my knowledge and belief it was understood.

Signature of Researcher: ______________________________________
Date:___/____/____

Appendix 3 - Rate of Perceived Exertion Scale

6	**No Exertion at All**
7	**Extremely Light**
8	
9	**Very Light**
10	
11	**Light**
12	
13	**Somewhat Hard**
14	
15	**Hard (Heavy)**
16	
17	**Very Hard**
18	
19	**Extremely Hard**
20	**Maximal Exertion**

(Borg, 1982)