Hyperthermic resistance training in semi-professional rugby athletes

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Abstract

Resistance training muscle adaptations may be enhanced under increased environmental temperatures (>30 °C). Training in the heat has been widely used to enhance performance adaptations in a range of populations from untrained to elite-athletes. Environmental heat stress is used to provide an additional training stimulus to the individual to potentiate greater physiological adaptations and subsequent athletic performance. Chapter One of this thesis reviews the current literature on different methods of thermal stress and how it could be implemented for preparation of rugby union athletes. Chapter Two of this thesis includes an original investigation whereby 18 elite, semi-professional rugby union athletes (age [mean ± SD], 22.2 ± 3.5 years; body mass 99.6 ± 11.5 kg; height 187.6 ± 6.4cm) performed a three-week resistance training intervention (12 sessions) where they were randomly allocated into two groups: HEAT (n = 8) with all lower-body resistance training sessions performed in environmental conditions maintained at 35 °C and 37% relative humidity (RH), or CON (n = 10) where the same training was performed in temperate conditions (21 °C and 45% RH). Pre and post-training intervention tests included measures of strength, power, endurance, speed, and body mass. When comparing groups, *small* effect sizes were found in favour of HEAT for the back squat (d = 0.26) and bench press (d = 0.23). All other measures were associated with *trivial* or *unclear* effects. A significant group x time interaction for body mass, associated with a *trivial* effect size (d = 0.19, HEAT +1.5 kg; CON -0.8 kg). Resistance training in the heat may lead to *small* improvements in lower and upper body strength compared to the identical training programme performed in temperate conditions. Utilization of heat stress during specific strength training sessions may prove to be a beneficial strategy to increase muscle adaptions for rugby union athletes.

Table of Contents

List of Tables

List of Figures

Abbreviations

Table 1. List of abbreviations

ATP	Adenosine triphosphate
BB	Barbell
CI	Confidence interval
cm	Centimeter
CMJ	Countermovement jump
CON	Control
FB	Full body
HEAT	Heat
hGH	Human growth hormone
iMTP	Isometric mid-thigh pull
KB	Kettlebell
kg	Kilogram
m	Meters
MBt	Medicine ball throw
min	Minute
$m \cdot s^{-1}$	Meters per second
mTOR	Mammalian target of rapamycin
N/A	Not applicable
NR	Not reported
RH	Relative humidity
RPE	Rate of perceived exertion
SD	Standard deviation
SL	Single leg
1RM	One repetition maximum
3RM	Three repetition maximum
°C	Degrees celsius

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Thesis Overview

The format of this thesis includes a chapter presented in the style of an individual journal article which it has been submitted for publication and consequently, some information may be repeated. This thesis consists of three chapters. Chapter One is a review of the current literature and introduces the reader to rugby union, heat research, and the notion of using an added thermal stress during resistance training to augment athletic performance. Chapter Two contains the present study of this thesis and investigates the effect of resistance training in the heat on physical performance in elite rugby athletes. This chapter is presented in the required format by the *Journal of Strength and Conditioning Research* where it has been submitted for publication. The final chapter, Chapter Three, concludes the findings of this thesis and provides the reader with practical applications and suggestions for future areas of research.

Chapter One

Literature Review

Introduction

The purpose of this literature review is to introduce the reader to the existing research on the sport of rugby union and its physical demands, resistance training for rugby athletes, and the potential physiological and performance benefits of exercise in the heat. Rugby union is a complex, open sport where athletes are required to have a range of ball handling and high impact contact skills, whilst performing multiple short and long distance sprints (23). This sport requires a compound training regime to ensure the athletes are properly prepared. A significant component of the rugby training programme is resistance work which has been proven to facilitate the development of strength, speed and power characteristics in this sport (5, 8, 32, 55).

One end goal of resistance training is to enhance performance potential. The body will adapt to the stress of exercise with increased fitness capacity if the stress is above a minimum threshold (11, 12). To improve an athlete's physical profile, training load must be above the minimum fitness threshold. Alternative methods of achieving increased training load, without overstressing the body, is manipulating the environmental conditions in which the exercise is conducted. The addition of a heat stress to exercise has been used by practitioners working with athletes for more than a decade (21, 46, 54). Exercise in the heat produces additional physiological adaptations, further enhancing performance (17, 46, 51). The notion of resistance training in heat providing additional physiological adaptations is still in its novelty and is yet to be investigated in elite rugby athletes over a training intervention.

Physical Demands and Characteristics of Rugby Union Athletes

Rugby is a multifaceted sport requiring a large range of skills and physical abilities to be performed successfully. Rugby athletes are required to perform repeated accelerations/decelerations, sprints, changes of direction and heavy contact-based activities such as tackling, static holds, scrums, rucks and mauls (23, 63). A large proportion of a rugby athletes training load is dedicated to on-field team trainings and various skill-based training sessions; hence, the need for resistance training to be as time effective (i.e. efficient) as possible (1, 8). Furthermore, practitioners working with rugby athletes are constantly searching for innovative methods of increasing physiological adaptations to enhance performance (1).

Previous research has shown that there is a substantial difference between college level and professional rugby athletes in upper body strength and power characteristics (3). Furthermore, it has been well established that resistance training facilitates the development of these abilities through improvements in strength, power and speed in rugby athletes (5, 8, 55). Baker and Newton (5) reported that first division rugby league players were stronger (17.0%), heavier (8.9%), more powerful (11.5%) and created more momentum (7.0%) than second division players. The authors also noted that increases in body mass alone does not account for the increased strength of the first division rugby league players, but rather it was the strength to body-weight ratio that was important. The first division players were stronger per kilogram body of body mass (1RM/kg: 1.78) in comparison to the second division players (1.64). The authors summarized that this increase may be caused by various neural, tissue/morphological, and/or maturation differences between groups. Harries, Lubans, Buxton, MacDougall and Callister (32) support the notion that there is a positive correlation between lower body strength and sprint performance in rugby athletes. Baker and Nance (4) investigated the relationship between running speed, strength and power measures in professional rugby league players during a preseason resistance training programme. The authors reported that three repetition maximum (3RM) power clean (hang) had a significant ($p < 0.05$) positive correlation to 10 meter running speed. Furthermore, 3RM squat jump also had a significant ($p < 0.05$) positive correlation to 40 meter running speed performance.

Resistance Training

Resistance training is a critical component to success in many team sports, including rugby union (40). Previous research provides compelling evidence that resistance training stress stimulates neuromuscular enhancements as the damage it causes to the muscle triggers the excretion of muscle building hormones such as growth hormone (GH), testosterone and cortisol to repair, rebuild and further strengthen the musculoskeletal system (11, 12, 42, 65). The concentration of such hormones excreted during/post resistance training is regulated by a number of concurrent factors; total muscle mass involved (31, 66), resistance training age (43, 64), intensity and volume (14, 41), individual muscular strength (43) and nutritional intake (44). It is known that various resistance training protocols can effectively enhance muscular hypertrophy, maximal strength, strength-endurance and power (12). Harries, Lubans, Buxton, MacDougall and Callister (32) demonstrated significant improvements to 10 and 20 meter sprint running performances following two resistance-training sessions per week for 12 weeks. The authors reported an increased resistance training frequency more than twice a week may have resulted in larger positive physiological adaptations and ultimately a greater sprint performance. Furthermore, Seitz, Reyes, Tran, de Villarreal and Haff (58) observed a moderate positive correlation with resistance training frequency and sprint performance. Furthermore, McMaster, Gill, Cronin and McGuigan (48) reported that resistance training frequency had a direct impact on the extent of rugby athletes lower power output development. Resistance training frequency of four times a week had the biggest power increase of 0.7%.

The effectiveness of a given resistance training programme is dependent on its structure. This involves balancing and fluctuating resistance training frequency, intensity, duration/time, type and volume to ensure positive muscular adaptations are achieved without overloading the athlete (11, 12). Frequency relates to how many training sessions per week the athlete completes. Intensity of the training session is how physically demanding the activity is. Duration/time is self-explanatory and is how long the training session takes. Finally, the type of training session describes what category of exercise will be performed.

Previous researchers have indicated a correlation with enhanced strength adaptations and increased training frequency (2, 11, 12). Hoffman, Deschenes, Kemp, Kraemer and Fry (35) reported a training frequency of four or five days per week resulted in the greatest amount of performance increases including maximal upper and lower-body strength. Whereas, six days per week showed signs of overloading and decreased physical performance, compared to five days per week. Additionally, resistance training protocols, with explosive components such as speed and plyometric training have previously shown that they are more effective at enhancing lower-body power than resistance training alone (32, 48, 59). Additionally, to these resistance sessions, rugby athletes are still required to perform two to three skill and team based sessions a week.

Physiological Effects of Heat Exposure Coupled with Exercise

Exercising in hot and humid environmental temperatures (>35 °C and >50% RH) forces the body to adjust its thermoregulatory processes to enhance thermal tolerance causing a number of physiological adaptations (46, 51). When exercise is performed in a controlled environmental chamber (i.e. heat chamber), it is known as heat acclimation (49). The physiological adaptations to heat exposure include: reduced cardiovascular strain, enhanced fluid balance, increased cellular protection, increased skin blood flow and enhanced sweat composition (49, 51).

Thermal stress coupled with exercise improves thermoregulation, reduces the risk of heat illness and improves submaximal exercise performance and maximal aerobic capacity. Moreover, exercise in the heat has been demonstrated to upregulate mammalian target of rapamycin (mTOR) signaling, crucial for initiating translation, facilitating protein synthesis (38, 52, 67) and enhance cytoprotective mechanisms (36, 45). Cytoprotective mechanisms are methods for cellular protection, and in this case, increasing cell's thermal tolerance (45). However, it is known that the mechanisms of heat shock protein 70, which facilitate cellular protection are unidentified (45). Gray, De Vito, Nimmo, Farina and Ferguson (30) demonstrated that increased muscle temperatures following a 30 minute passive immersion in hot water (42.8 °C) increased adenosine triphosphate (ATP) turnover and muscle fiber contraction velocity (53). The authors reported that the increased ATP turnover rate observed, was most likely caused by an upregulation in cross-bridge cycling, as myofibrillar ATP synthase activity is dependent on temperature (33, 61). Previous research has observed this result during intense dynamic exercises (25) and isometric contractions (24).

Training in the heat has been primarily used by athletes to enhance aerobic performance (46, 57, 62). Ball, Burrows and Sargeant (6) investigated the effect of acute heat stress on repeated (30 second) sprint cycle performance in moderately trained individuals. The authors reported that both average and peak power was significantly higher, 15% and 25% respectively, in the heated environment (30.1 °C and 55% RH) than attained in a temperate environment (18.5 °C and 40%

RH). These findings are in agreement with Castle, Mackenzie, Maxwell, Webborn and Watt (18) who used 10 days of cycling training with a thermal stress (33 °C and 52% RH). The authors observed a significant increase in peak power output during intermittent sprints in the heated condition. Additionally, Ball, Burrows and Sargeant (6) reported a deterioration of power between the first and second trials were significantly (p < 0.01) higher in the heated environment in comparison to temperate conditions. Ball, Burrows and Sargeant (6) also observed an increased power production with thermal stress concomitantly with a reduction in muscular endurance under the thermal stress. These findings are in agreement with past literature (53). Moreover, Girard, Brocherie and Bishop (27) reported that acute heat exposure may benefit short term/initial maximal power output, but could inhibit performance completing repeated efforts.

Resistance Training in the Heat

Minimal research has been conducted on resistance training in the heat (17, 68), and to our knowledge no studies have examined the effects of resistance training in the heat in rugby union athletes. Casadio, Storey, Merien, Kilding, Cotter and Laursen (17) assessed the acute effect of resistance training in heat (30 °C and 40-60% RH) on highly trained power athletes. The study implemented a randomised crossover trial with a wash out period of 5-7 days. Resistance based sessions consisted of power cleans (3 sets of 85-90% 1RM), parallel back squats (3 sets of 85-90% 1RM), vertical jumps, bench press (3 sets of 85-90% 1RM) and seated medicine ball throws (3 sets of 85-90% 1RM). The authors found resistance training in the heat caused enhanced power production, and increased maximal force. In comparison, Hedley, Climstein and Hansen (34) showed that muscular power increased significantly (p < 0.05) following acute heat exposure. The authors assessed the acute effects of a 30-minute sauna (65-75 °C and 15% RH) on muscular strength, muscular endurance and muscular power in ten resistance-trained athletes. The authors reported no difference in upper-body strength between the two groups, however discovered a significant ($p < 0.05$) decrease in lower body muscular strength following exposure to the sauna. Both upper and lower-body muscular endurance significantly ($p < 0.05$) decreased for the sauna group.

Several studies have investigated progressive hyperthermic resistance training in untrained (34, 60) and elderly (68) populations, and results were equivocal across control and experimental groups. It is widely known that highly trained athletes have less adaptation potential, thus additional environmental stress may passively increase this adaptation threshold and increase performance (17). There is no literature assessing the differences in performance after completing a three-week hyperthermic resistance training intervention in highly trained athletes. The novel concept of the present study is to implement a hyperthermic resistance training intervention in highly trained rugby union athletes.

Table 2. Summary of studies investigating hyperthermic resistance training on performance.

Author	Heat Stimulus	Heat Application	Total Duration	Temperature	Exposure Time (days)	Control Group	No. of Participants	Sport	Training Status	Performance Test	Effect Size	P-value
Stadnyk, Rehrer, Handcock, Meredith-Jones and Cotter (60)	Electric pad – Quadriceps	During and after exercise	>20 min	38 °C	30 sessions over 12 weeks	Yes – Contralateral-limb study	10	N/A	Untrained	↑ 3RM Peak Concentric torque	NR	NR
Yoon, Lee, Lee and Lee (68)	Heated sheets – Quadriceps	Pre, during, and after exercise	8 hours	39 °C	36 sessions over 12 weeks	Yes - Temperate	29	N/A	Untrained	↑ 1RM Leg Extension	NR	($p < 0.05$)
Hedley, Climstein and Hansen (34)	Heated/dry sauna	Pre exercise	30 min	65-70 °C	1 session of 30 minutes	Yes – Temperate	10	N/A	Untrained	↑ 1RM Leg Press ↑ Vertical Jump	NR	($p < 0.05$) ($p < 0.05$)
Casadio, Storey, Merien, Kilding, Cotter and Laursen (17)	Heated room	During exercise	NR	30 °C	1 session of 70-90 minutes	Yes – Randomized crossover controlled trial	16	Athletics Netball Weightlifting Power Lifting	Highly Trained	↑ iMTP ↑ CMJ ↑ MBt	*moderate* *moderate* *small*	($p < 0.05$) ($p < 0.05$) ($p < 0.05$)

1RM: 1 repetition maximum, 3RM: 3 repetition maximum, iMTP: isometric mid-thigh pull, CMJ: countermovement jump, MBt: medicine ball throw, N/A: not applicable, NR: not reported, ↑: increased performance. Effect size thresholds of <0.2, 0.2, 0.5, 0.8 for *trivial*, *small*, *moderate and large*, respectively (19).

Summary

Rugby union is a multifaceted sport which demands the athletes to have a vast range of abilities and skills (23), providing the practitioners working with rugby athletes with numerous challenges. Strength, power and speed are all crucial aspects to success in rugby union, and it is well established that resistance training facilitates the development of these attributes (8, 12, 40). The addition of heat to an athlete's endurance based training regime has been extensively investigated for longer than a decade (21, 46, 54). The literature on this topic provides strong evidence supporting the notion that exercise in the heat may improve cardiovascular capabilities in athletes (18, 34, 46). It is evident that hyperthermic exercise can produce and upregulate multiple hormones (38) and enzyme mechanisms (36, 45) facilitating the rebuilding and development of the musculoskeletal system (67). Hyperthermic resistance training literature is exceedingly scarce, however there are trends toward positive results from limited studies. Casadio, Storey, Merien, Kilding, Cotter and Laursen (17) support this notion as they showed acute hyperthermic resistance training enhanced power and maximal force production. This indication of physiological benefits observed from hyperthermic resistance training warrants further investigation.

Chapter Two

Resistance Training in the Heat Improves Strength in Trained Rugby Athletes

This chapter appears in the same format which was required by the *Journal of Strength and Conditioning Research* where it has been submitted for publication.

Abstract

Resistance training muscle adaptations may be enhanced under increased environmental temperatures (>30 °C). Eighteen elite, semi-professional rugby union athletes (age [mean ± SD], 22.2 ± 3.5 years; body mass 99.6 ± 11.5 kg; height 187.6 ± 6.4cm) performed a three-week resistance training intervention (12 sessions). The participants were randomly allocated into two groups: HEAT (n = 8) performed all lower-body resistance training sessions in environmental conditions maintained at 35 °C and 37% RH, or CON (n = 10) where the same training was performed in temperate conditions (21 °C and 45% RH). Pre and post-training intervention tests included measures of strength, power, endurance, speed, and body mass. When comparing groups, *small* effect sizes were found in favour of HEAT for the back squat (d = 0.26) and bench press (d = 0.23). All other measures were associated with *trivial* or *unclear* effects. A significant group x time interaction for body mass, associated with a *trivial* effect size (d = 0.19, HEAT +1.5 kg; CON -0.8 kg). Resistance training in the heat may lead to *small* improvements in lower and upper body strength compared to the identical training programme performed in temperate conditions.

Keywords: environmental chamber, strength, jump performance, sprint ability

Introduction

Strength and power gains achieved through resistance training is a critical component to success in many team sports, including semi-professional rugby union (48). Rugby is a multifaceted sport requiring a large range of skills and physical abilities to be performed successfully. Rugby athletes are required to perform repeated accelerations/decelerations, sprints, changes of direction, and heavy contact based activities such as tackling, static holds, scrums, rucks and mauls (23, 63). It is evident that resistance training facilitates the development of these abilities through improvements in strength, power and speed in rugby athletes (5, 8, 55).

As a large proportion of rugby training is dedicated to on-field, team and various skill-based training sessions. Hence, specific resistance training needs to be as time effective as possible (1, 8). Furthermore, practitioners working with rugby athletes look to innovative time-efficient methods of increasing physiological adaptations to enhance performance (1). It is known that a resistance-training stimulus promotes muscle growth, whereby mechanical and endocrine inputs are integrated to repair, rebuild and further strengthen the neuromuscular system (11, 12, 65). Manipulating the environmental conditions (i.e. heat and humidity) has been shown to increase additional physiological stress, and in turn, augment training adaptations, without increasing training intensity or volume (16, 18, 26). It could be that the combination of resistance training and heat stress has the potential to further enhance muscle growth, and improve physical performance.

Training in the heat has been primarily used by endurance athletes to enhance aerobic performance (46, 57, 62). Exercising in heated (~35 °C) environmental conditions forces the body to adjust its thermoregulatory processes to enhance thermal tolerance, causing a number of subsequent physiological adaptations (46, 51). The physiological adaptations to heat exposure include: reduced cardiovascular strain, enhanced fluid balance, increased cellular protection, increased skin blood flow and enhanced sweat composition (49, 51).

Minimal research has been performed assessing the use of increased environmental temperatures whilst completing a resistance-training programme in trained athletes. Casadio, Storey, Merien, Kilding, Cotter and Laursen (17) assessed the acute effect of heated (HOT: 30 °C and 40-60% RH) resistance training in highly-trained power athletes compared to the same training in temperate conditions (CON: 20 °C and 40-60% RH). The resistance based sessions consisted of power cleans (3 sets of 85-90% 1RM), parallel back squats (3 sets of 85-90% 1RM), vertical jumps, bench press (3 sets of 85-90% 1RM) and seated medicine ball throws (3 sets of 85-90% 1RM). The authors found resistance training in the heat caused *moderate* increases in both power production (8.2%) and maximal force (4.4%) in female athletes. However, power production and maximal strength were *unclear* for the male athletes between the HOT and CON groups. Plasma human growth hormone (hGH) concentration showed a *small* likely increase for both females (85%) and males (107%) in favour of the HOT group compared to CON. hGH is an anabolic hormone which facilitates regeneration of damaged muscle fibers, inducing structural changes such as increased muscle size and muscular strength (11, 28). Previous research suggests that increases in core body temperature and exercise intensity may effect plasma hGH (42). Furthermore, these stimuli concurrently increase blood flow (50) and thus enhance transport of hGH to the skeletal muscle which may facilitate anabolic processes (15, 29).

Existing research on a resistance training protocol in the heat is scarce, especially assessing the effects on trained athletes. Multiple studies have assessed the effects in untrained or even elderly populations using alternative ways to acquire the heat stress such as heat pads, sheets, and saunas. Stadnyk, Rehrer, Handcock, Meredith-Jones and Cotter (60) investigated the effects of heat (30 sessions) during a progressive resistance training intervention in untrained adults over 12 weeks. The authors used a contralateral-limb as a control, where one thigh was heated (>38 °C) during and 20 minutes after each session. The direct heat application was attained using an electric heating pad applied to increase muscle temperature. This study reported no differences between groups for lean muscle mass, muscular strength, peak isokenetic torque and rate of torque development. However, given that the participants were untrained, they may respond differently to trained populations.

Contradicting results regarding the use of heat during resistance training in the literature, coupled with the fact that there is limited research on the chronic application of such an intervention in highly-trained athletes, the aim of the present study was to investigate the physiological and performance effects of three weeks of resistance training in the heat (~35 °C) compared to a control group (~21 °C) in elite rugby union athletes. The hypothesis of the present study is resistance training with an added heat stimulus will cause an additional physiological and performance benefit in resistance-trained rugby union athletes.

Methods

Experimental approach to the problem

The present study implemented a randomized, controlled, parallel-group design over a period of five weeks during the Southern Hemisphere summer (January to February). All participants resided in temperate conditions throughout the duration of the study (19 ± 9 °C and 70 ± 44% RH) and had no previous exposure to environmental heat over 30 °C in the six months leading up to the study. The study period included a week of pre-testing, three weeks of resistance 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. Both the experimental (HEAT) and control (CON) groups performed the same block of structured resistance training volume and intensity over the three-week intervention period.

Subjects

Eighteen elite semi-professional rugby union athletes (age [mean ± SD], 22.2 ± 3.5 years; body mass 99.6 ± 11.5 kg; height 187.6 ± 6.4cm) were split into two groups: HEAT (n = 8) and CON (n = 10). Groups were assigned based on an even distribution of forwards and backs in each group. All athletes were from the same rugby union squad, which played in New Zealand's top provincial competition. All athletes volunteered to take part in the present study. This study was conducted during transition from the off-season to pre-season phase of the competition, where the athletes had not been prescribed any physical activity/training in the previous four weeks. 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 21 participants;

however, three were withdrawn from the study due to injuries sustained during activities unrelated to the study.

Procedures

Loading parameters and exercises for both groups are outlined in Table 3. The HEAT group performed all lower-body resistance training sessions in a climate-controlled chamber (All Seasons Air Conditioning Ltd., Tauranga, New Zealand), set to 35 °C and 37% RH; whereas the CON group performed all 12 lower-body resistance training sessions under temperate conditions using the same equipment (21 ± 1 °C and 45 ± 6% RH) (Table 3). Both HEAT and CON groups proceeded to perform the remainder of the resistance training programme (upper-body) in temperate conditions. The remainder of the programme consisted of weighted chin-ups (3 sets of 2-4 reps), dumbbell shoulder press (3 sets of 2-4 reps), bench press (3 sets of 2-4 reps), hammer row (machine; 3 sets of 2-4 reps), barbell military press (3 sets of 2-4 reps) and weighted dips (3 sets of 2-4 reps). Both HEAT and CON groups had an additional upper-body hypertrophy session per week which consisted of dumbbell incline press (4 sets of 6-8 reps), dumbbell Arnold press (4 sets of 6-8 reps) and single arm dumbbell row (4 sets of 6-8 reps). To investigate any differences in perceived intensity between groups, the rate of perceived exertion (RPE) was assessed at the completion of each training session using the Borg 6-20 RPE scale (13). Perceived tolerance to the environmental conditions were assessed for both groups during each training session. The 1-10 thermal comfort scale was implemented to investigate the differences between groups.

Testing

Testing was carried out over one week in the athlete's normal environmental conditions. All participants were familiar with the testing procedures and protocols. On day one, body mass, upper and lower body one repetition maximum (1RM) strength were assessed during the bench press, back squat and weighted chin-ups. On day four, the bodyweight countermovement jump (CMJ) and 10-meter sprint trials were performed. On day five, the Bronco fitness test was performed. All physical performance tests were preceded by a standardized test specific warm-up (Table 3).

Maximum strength was measured via the 1RM 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 guidelines of (2). All 1RM attempts were visually assessed by the same researcher. During the back squat, the athlete was required to descend to a parallel depth (i.e. femur was parallel to the floor) and return to full extension of the back, hips and knees. During the bench press, the bar must be lowered to the chest in a controlled manner ('bouncing the bar' off the chest was not permitted) and then return to full extension of the elbows. During the weighted chin up, the chin was required to ascend above the bar from full extension in the elbows. The exercises were performed in sequential orders as listed above (squat, bench press, chin-up) and was maintained for the two testing sessions.

Table 3. Testing and training schedule for both HEAT and CON groups for the duration of the study.

Week	Monday	Tuesday	Thursday	Friday
1 Pre Test	Back squat 1RM Bench press 1RM Weighted chin-up 1RM Body mass		Bodyweight CMJ 10 meter sprint	Bronco fitness test
2	Uni-Lateral Strength: Bulgarian split squat (each side) (4 x 8 @ 70% 1RM) Pistol squat (each side) (4 x 4) 3 minutes rest after each super-set	Bi-Lateral Strength: Back squat (5 x 3 @ 85% 1RM) SL calf raise (5 x 8) 3 minutes rest after each super-set	Posterior Strength: Romanian deadlift (4 x 8 @ 70% 1RM) BB hip thrust (4 x 8) 3 minutes rest after each super-set	Uni-Lateral Strength: Bulgarian split squat (each side) (4 x 8 @ 70% 1RM) Pistol squat (each side) (4 x 4) 3 minutes rest after each super-set
3	Posterior Strength: Romanian deadlift (4 x 8 @ 70% 1RM) BB hip thrust (4 x 8) 3 minutes rest after each super-set	Bi-Lateral Strength: Back squat (5 x 4 @ 85% 1RM) SL calf raise (5 x 8) 3 minutes rest after each super-set	Uni-Lateral Strength: Bulgarian split squat (each side) (4 x 6 @ 80% 1RM) Pistol squat (each side) (4 x 4) 3 minutes rest after each super-set	Posterior Strength: Romanian deadlift (4 x 6 @ 80% 1RM) BB hip thrust (4 x 8) 3 minutes rest after each super-set
4	Bi-Lateral Strength: Back squat (5 x 5 @ 85% 1RM) SL calf raise (5 x 8) 3 minutes rest after each super-set	Uni-Lateral Strength: Bulgarian split squat (each side) (4 x 6 @ 80% 1RM) Pistol squat (each side) (4 x 4) 3 minutes rest after each super-set	Bi-Lateral Strength: Back squat (4 x 4 @ 85% 1RM) SL calf raise (5 x 8) 3 minutes rest after each super-set	Posterior Strength: Romanian deadlift (4 x 6 @ 70% 1RM) BB hip thrust (4 x 8) 3 minutes rest after each super-set
5 Post Test	Back squat 1RM Bench press 1RM Weighted chin-up 1RM Body mass		Bodyweight CMJ 10 meter sprint	Bronco fitness test

All exercises are represented as sets x repetitions. FB = full body; 1RM = one repetition maximum; CMJ = counter movement jump; SL = single leg; KB = kettle bell; BB = barbell.

A countermovement jump (CMJ) was used to test lower body velocity capabilities. Athletes started with both feet on the floor, placed at shoulder width apart with both hands on a wooden bar placed across the upper trapezius. Athletes were instructed to perform five cyclic vertical CMJ's utilizing a self-selected depth, aiming for maximum height with each jump (20). The highest CMJ peak velocity ($m \cdot s^{-1}$) 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 placed on the floor. The Gymaware is highly reliable and precise for measuring displacement and velocity as assessed using typical error measurement (0.00 m) (69).

Sprint acceleration ability was tested over 10m from a standing split-stance start stance positioned 30cm behind the first set of timing gates. Participants performed three maximum effort trials, the fastest time was recorded for subsequent analysis. Sprint times were measured using single beam infrared timing lights set to a height of 0.73m (TC-Timing System, Brower, Draper, Utah, USA). The inter-trial reliability (r = 0.86) of the above procedure has been previously established at (4).

The Bronco test was performed pre and post-training intervention to assess high intensity aerobic fitness. The Bronco test is widely used in the rugby environment and consists of running 1200 meters in a shuttle-type fashion (~5 min in duration). Cones were placed at the 0m, 20m, 40m, and 60m lines. Athletes were required to run from 0 to 20m, return to the 0m line, run to the 40m line and return to the 0m line, run to the 60m line and return to the 0m line. Completion of the 20-40-60m shuttles was considered one repetition, with athletes completing five repetitions as quickly as possible to finish the test. Hand held stop watches were used to record the Bronco finishing times. A 5-minute field test was performed as it is easy to apply and a practical test for this setting (10).

Statistical analyses

Statistical analyses were performed using the Statistical Package for Social Science (V. 22.0, SPSS Inc., Chicago, IL). Descriptive statistics are shown as means ± standard deviations unless stated otherwise. A two-way repeated measures ANOVA was performed to determine the effect of different conditions (HEAT 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 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 for between group comparisons. 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, 0.2-0.5, 0.5-0.8, >0.8 for *trivial*, *small*, *moderate, and large*, respectively (19). An effect size of ±0.2 was considered the smallest worthwhile effect. The effect was deemed *unclear* if its 90% confidence interval overlapped the thresholds for *small* positive and negative effects (7). Statistical significance was set at $p \leq 0.05$ for all analyses.

Results

There were no statistically significant differences between groups for pre-test values for any of the measured variables ($p > 0.05$). The average session exposure duration, mean temperature and RH across the 12 sessions was 33 ± 4 min, 35 ± 1 °C, and 37 ± 3% RH, respectively for the HEAT group; and N/A, 21 ± 1 °C and 46 ± 6% RH for the CON group. There were no significant differences in RPE between the HEAT (13.8 ± 1.6) and CON (13.7 ± 1.1) groups for the duration of the study. However, there was a significant difference ($p < 0.01$) in thermal comfort between the HEAT (9.5 ± 0.9) and CON (2.4 ± 0.9) groups.

There were no significant two-way interactions between treatment and time for any of the measured variables ($p > 0.05$), except for body mass ($p = 0.01$, Table 4), which was significantly increased in HEAT compared to CON over the study period. As highlighted in Figure 1, there were *small* between-group effects in favour of the HEAT compared to CON for the bench press ($d = 0.23$) and back squat strength ($d = 0.26$). *Small* to *moderate* significant ($p < 0.05$) within group improvements were seen in the HEAT group for bench press ($d = 0.25$), Bronco ($d = 0.33$), back squat ($d = 0.45$), and jump squat ($d = 0.66$) (Table 4); whereas, a *small* non-significant performance change was observed in the CON group for the jump squat ($d = 0.33$). The remaining results were *trivial* non-significant performance changes for the CON group ($p > 0.05$; $d = 0.06 - 0.15$).

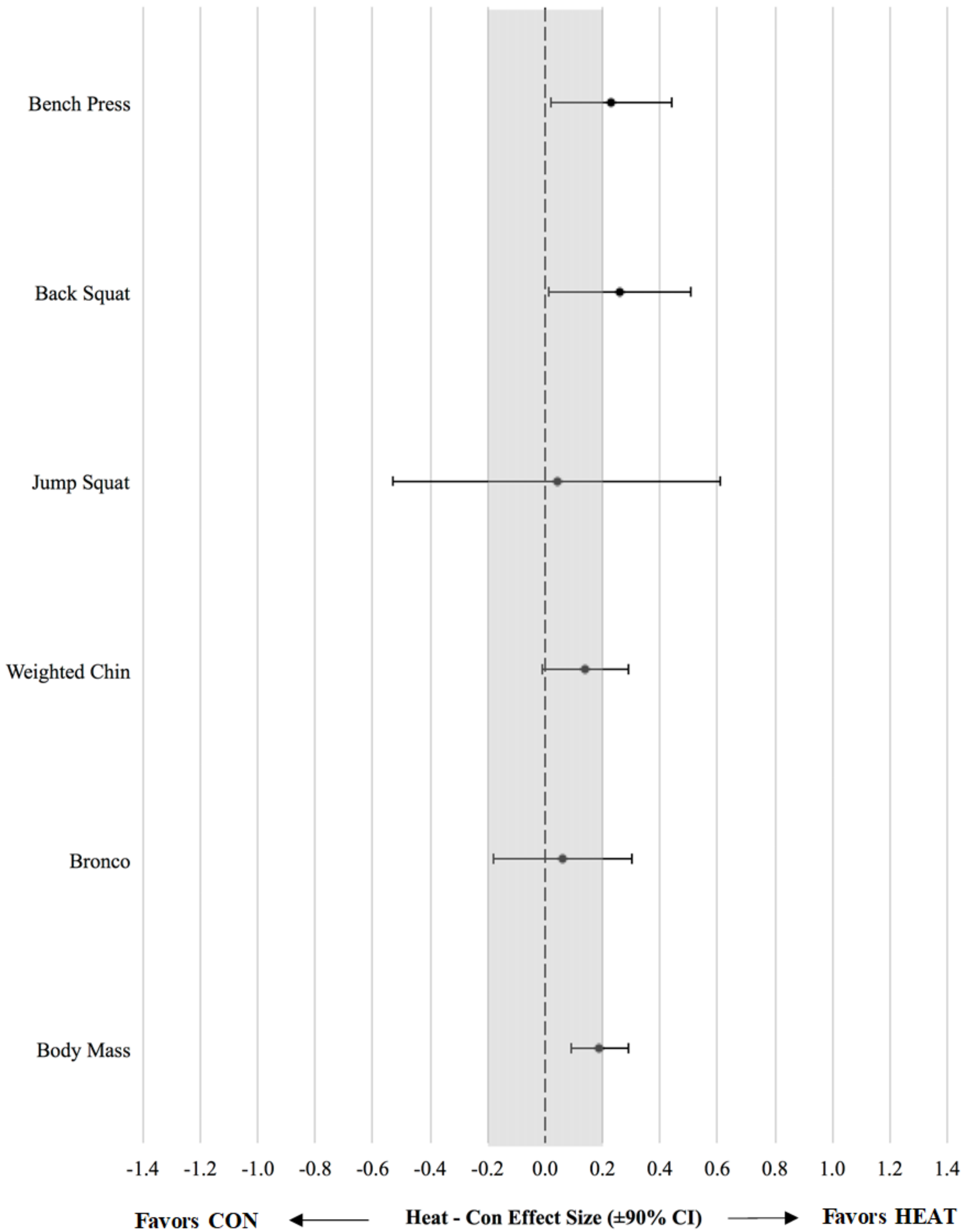

Figure 1. Effect sizes for measured variables between HEAT – CON groups. Error bars represent 90% confidence intervals (±90% CI), with the shaded area representing a *small* effect (±0.2) between groups. Where 90% confidence intervals overlap *small* positive and negative effects, the result was deemed *unclear*. # = *small* effect.

Table 4. Pre and post measures (mean ± SD) for HEAT and CON groups and comparison of the change between groups (±90% confidence intervals) and effect sizes.

	HEAT (mean ± SD)			CON (mean ± SD)			ΔHEAT - ΔCON (mean ±90%CI) Effect size
	Pre	Post	*d*	Pre	Post	*d*	
Bench Press (kg)	127 ± 24	133 ± 23#	0.25 *small*	123 ± 15	124 ± 17	0.06 *trivial*	4 ±4 0.23 *small*
Back Squat (kg)	173 ± 20	182 ± 19#	0.45 *small*	155 ± 20	158 ± 20	0.15 *trivial*	6 ±6 0.26 *small*
Jump Squat ($m \cdot s^{-1}$)	3.8 ± 0.3	4.0 ± 0.4	0.66 *moderate*	3.6 ± 0.3	3.7 ± 0.3	0.33 *small*	0.02 ±0.2 *0.04* *unclear*
Weighted Chin (kg)	144 ± 9	146 ± 8#	0.22 *small*	135 ± 13	136 ± 14	0.07 *trivial*	2 ±2 0.14 *trivial*
Bronco (seconds)	303 ± 18	297 ± 26	-0.33 *small*	316 ± 37	311 ± 38	-0.13 *trivial*	1 ±7 0.02 *unclear*
Body Mass (kg)	103.8 ± 12.2	105.3 ± 12.4#	0.12 *trivial*	101.4 ± 11.8	100.6 ± 11.8	-0.06 *trivial*	2 ±1* 0.19 *trivial*

Represents significant difference between pre and post ($p<0.05$), * Represents significant intervention x time interaction between groups ($p<0.05$).

Discussion

The present study is the first to evaluate the effect of heated resistance training in an elite-athlete setting over a short three-week training phase. The HEAT group in the present study demonstrated *small* improvements in the bench press and back squat strength when compared to the CON group. These findings suggest that performing lower body resistance training in an environmentally controlled chamber set to hot (35 °C and 37% RH) conditions can potentiate improvements in both lower and upper body strength compared to the same training in temperate conditions in elite rugby athletes.

The increased maximal strength may be a result of the heat stress, which stimulates production and activation of heat shock protein 72, facilitating protein and muscle synthesis (28, 29, 39). Furthermore, Kakigi, Naito, Ogura, Kobayashi, Saga, Ichinoseki-Sekine, Yoshihara and Katamoto (38) reported mTOR signaling was improved with the addition of heat to resistance training in human skeletal muscle. In the present study the HEAT group only performed the lower-body resistance training in the heated conditions. The HEAT group then proceeded to complete the remainder (upper-body) of the resistance training programme in temperate conditions. Interestingly, the HEAT group showed *small* improvements in bench press strength compared to the CON group. The neuromuscular/endocrine responses from the heat stimulus may explain this outcome as neither group performed any upper-body exercises while exposed to heat (29, 38). Additionally, Hedley, Climstein and Hansen (34) reported a significant ($p < 0.05$) increase in muscular power following acute heat exposure. The increased upper-body strength observed in the present study suggests that the heat primed/potentiated subsequent work.

The present study also observed mulitple *small* increases between the pre and post testing for the HEAT group in lower-body strength (back squat), upper-body strength (bench press and weighted chin-ups), and aerobic capacity (Bronco). In addition, a *moderate* increase in jump squat ($d = 0.66$) between the pre and post testing was observed for the HEAT group. These findings agree with previous research reporting enhanced power production from resistance training with addition of heat stress (17, 34, 46). Ball and colleagues indicated increased muscle fibre temperature may facilitate increased contraction velocity and thus, power output (6). Furthermore, Gray, De Vito, Nimmo, Farina and Ferguson (30) reported an increased power production following passive heating. The authors concluded, the increased muscle temperature caused an improved rate of anaerobic ATP turnover and muscle fibre conduction velocity, and thus a greater power production. The present study measured bar velocity ($m \cdot s^{-1}$) for the jump squat. The HEAT group produced a *moderate* increase in bar velocity from pre to post testing, which confirms hyperthermic resistance training can facilitate increased power production.

Given the athletes in the present study were highly trained, it is improbable that the performance increases were due to neural adaptations alone (11). Therefore, the performance increases were likely due to a combination of an effective resistance training programme and the potential additional effects of the heated training environment (35 °C and 37% RH). For instance, exercise in the heat has been demonstrated to accentuate the acute response of the anabolic hGH (17) and upregulate mTOR signaling (38). This may explain the improved maximal strength in the present study observed for the HEAT group compared to the CON.

The investigation into resistance training in the heat is still relatively new in the literature and hence, a limited amount of research has been reported. Future research is required to develop knowledge around the benefits of resistance training in the heat. Future research in this area should investigate resistance training in heat using a longer intervention protocol, with greater total exposure to the heat. Evidence surrounding the best method to obtain/apply the heat stress is still unknown (e.g. heated pads/sheets, heated chamber/room, heated suit). Given previous research has suggested that immune function may be impaired through acute training in the heat, future research should also monitor athlete health during such an intervention (51).

A limitation of the present study was the relatively small sample size. Given the elite nature of the participants, it was always going to be difficult to obtain enough participants to have a higher likelihood of producing a statistically significant results. Other limitations of the present study include the lack of nutritional control, and the lack of a placebo group. Of course it would be difficult to have a placebo group in a study investigating resistance training in the heat, therefore, the potential placebo effect cannot be discounted and may contribute to the small benefits seen in the HEAT group.

In conclusion, lower-body resistance training in a heated environment facilitated beneficial short-term changes in both upper and lower-body strength, in highly trained rugby athletes. The possible mechanisms and physiological adaptations for these *small* performance improvements should be investigated further in a longer-term training study.

Chapter Three

Conclusion, Practical Applications and Future Research

Conclusion

In the literature review (Chapter One) it is evident hyperthermic exercise stimulates hormonal production and release, and upregulates enzyme activity causing improved anabolic pathways including protein synthesis. Although only limited studies have investigated hyperthermic resistance training, the limited literature available does suggest this type of training can produce additional physiological benefits. The study presented in this thesis (Chapter Two) was designed to assess the effect of resistance training in the heat on the physical performance of elite rugby union athletes. The investigation discovered that resistance training in a heated environment (35 °C) over a three-week period lead to *small* increases in upper and lower body strength compared to the same resistance training in temperate conditions. The present study is the first to investigate the potential additive benefit from resistance training and heat in elite, strength-trained athletes. The mechanisms producing this additive benefit aren't completely understood. Furthermore, hormonal testing would have provided additional data/evidence determining whether these physiological adaptations were systemic effects (9, 22, 56) or persistent improvement in the force-velocity profile (37). Resistance training in increased environmental conditions may offer a logistical and effective training method of increasing strength and provoking muscle hypertrophy.

Practical Applications

The study presented in Chapter Two adds to the knowledge base, showing that resistance training in the heat may lead to *small* increases in lower-body strength and potentiate upper-body strength over a three-week period. Resistance training in heated (~35 °C) temperatures could be beneficial for elite rugby athletes during the competitive season when time is limited. This type of resistance training allowed athletes to work maximally, with small levels of thermal strain, without impeding on athlete's performance. Practitioners working with athletes may use a heated room for more than 30 minutes, three times a week to potentially enhance the physiological benefits obtained from resistance training. However, a heated chamber/room may have limited space. Practitioners should also consider the use of saunas, hot spas, and thermal clothing during exercise to help achieve the additional hyperthermic stress.

Future Research

- Finding significant, *small* improvements in performance favouring the hyperthermic group warrants further investigation, especially implementing the same protocols with a longer training intervention. Future research should utilize longer training protocols (> four weeks) with multiple performance/adaptation measures to assess the potential ergogenic effect of resistance training in the heat. For example, testing would occur pre-intervention, weekly during the intervention, and post-intervention. Longer interventions allow for potentially larger physiological benefits. Implementing an increased testing frequency will produce evidence outlining where/when the most significant gains and plateaus in the athlete's performance have occurred throughout the intervention.
- Physiological measures (saliva, blood, urine, muscle biopsies) should be added to investigate the mechanistic changes associated with any performance benefits observed in the hyperthermic group of the present study. Saliva is commonly used to measure cortisol and testosterone. Blood samples will provide insight to cytoprotection, muscle cell adaptations, fluid balance, heat shock proteins and human growth hormone. Urine specific gravity is extensively used by practitioners working with elite athletes which provides

information on the kidney's ability to concentrate urine. From this the practitioners are able to establish whether they are overtraining the athlete or not.

- Different methods of acquiring a hyperthermic stress on resistance training would identify which is the best hyperthermic protocol to improve athlete's performance. Different sources are but not limited to; heated/electric pads (specific muscle temperature), heated or heat retaining clothing (core-body temperature), heated environmental chamber (core-body temperature).
- Different timing to add the hyperthermic stress is something that requires investigation. The effect post-resistance exercise heating using saunas or spas to add stress may be an effective way to gain additional physiological benefits from the resistance training.
- Mayo, Miles, Sims and Driller (47) observed *small* improvements towards physical performance in elite rugby athletes following the same type of resistance training in a hypoxic environment. Future research should compare the hyperthermic and hypoxic resistance training methods in elite athletes.
- The study in Chapter Two investigates the effects of hyperthermic resistance training during the pre-season of the athlete's schedule. Future research should assess whether hyperthermic resistance training is also beneficial during a rugby season, where minimal improvements would be expected to be made.

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Appendices

Appendix 1 – Ethics approval

The University of Waikato
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Human Research Ethics Committee & Human Research Ethics Committee (Health)
Julie Barbour
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Email:humanethics@waikato.ac.nz

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: Assessing the effects of resistance training in the heat.

Principal Researchers: Cory Miles, Brad Mayo, 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 authorized part of the research programme 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 Cory Miles 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, G.A., (1982). Physiological basis of physical exertion. *Medicine and Science in Sport and Exercise,* 14, p 377.

Appendix 4 – Thermal Comfort Scale

Thermal Comfort Scale

How comfortable do you feel with the temperature of your body?

1	**Comfortable**
2	
3	**Slightly Uncomfortable**
4	
5	**Uncomfortable**
6	
7	**Very Uncomfortable**
8	
9	**Extremely Uncomfortable**
10	

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