METABOLIC AND PHYSIOLOGICAL RESPONSES TO UNWEIGHTED RUNNING

A Thesis

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by

Neil Panchal

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Department of Kinesiology

Abstract

of

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Purpose

The purpose of this study was to examine the metabolic and physiological effects of running at three different percentages of body-weight (BW): 100, 75, & 50 on a lower body positive pressure treadmill (LBPPT).

Methods

Twelve healthy college aged students, 6 male and 6 females, on a current training regimen and current/previous competitive experience participated in the study. The participants performed three graded exercise tests (GXT) using a custom protocol following a Latin Square design. Variables analyzed in the study included absolute VO_{2max} (L/min), HR_{max} (bpm), maximal oxygen saturation (%), maximal RPE, test performance (minutes), O_2 pulse, and VT_1 & VT_2. A 3 x 2 mixed-model RM-ANOVA was used to compare main effects of within-subject differences (BW-3) and between-subject differences (gender-2).

Results

No significant differences were seen in VO_{2max} and VT_1 & $_2$ (bpm) between the BW percentages ($p>0.05$). HR_{max} was significantly different between the 100-75 & 100-50 %BW comparisons. Average HR_{max} at 100%: 186±7.8, 75%: 183±7.5, & 50%: 182±7.7. Maximal RPE showed significance in the 100-50 & 75-50 comparisons. Maximal oxygen saturation showed significance in the 100-75 & 100-50 comparisons. Average SaO_2 at 100%: 96±1.5, 75%: 97.7±1.2, & 50%: 97.9±0.9. Significant differences were also seen in performance between 100-75, 100-50, & 75-50 comparisons. Average performance at 100%: 11.4±1.5, 75%: 14.1±1.8, & 50%: 16.6±1.5. Based on the percent of their HR_{max}, VT_1 was significant in 100-75 & 100-50 comparisons while VT_2 was significant in men only at 100-50 comparison.

Conclusion

Based on these results, it appears that training at a lower percentage of BW can lead to similar cardiopulmonary adaptations achieved at 100% BW, without the same level of stress applied, supporting the rationale behind conducting the study. Increased pressure from the LBPPT applied to the lower extremity may have acted as a mechanism in increasing venous return which in turn increased the stroke volume and caused the decreased HR_{max} in the participants. Lower HR_{max} and increased performance time may also indicate training at a lower percent of BW may allow individuals to sustain a prolonged steady-state at a similar intensity at 100% BW potentially allowing for an extended stimulus applied to the working musculature improving overall performance.

________________________________, Committee Chair
Daryl Parker, PhD

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Date

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TABLE OF CONTENTS

Chapter

LIST OF TABLES

Tables Page

LIST OF FIGURES

Figures Page

Chapter 1

INTRODUCTION

Although the activity of running has been popular since the early 70s, the number of runners and running events has seen a dramatic increase since the mid-2000s (Van der Worp, ten Haaf, van Cingel, Wijer, Sanden, & Staal, 2015). Because running is one of the most efficient ways to achieve physical fitness and linked to longevity, individuals of all ages and fitness categories can adopt this method of exercise (Van der Worp et al., 2015). Since running continues to grow in popularity, it is also extremely important to understand and appreciate the risk of different running injuries. Sport injuries, as a result of running, are often recurrent and there is wide recognition that a subsequent injury can be highly influenced by a previous injury (Finch & Cook, 2013).

A wide variety of sport injuries exist, but the primary form seen in many endurance athletes are overuse injuries. Overuse injuries, also classified as chronic injuries, is a category of sport-related injuries that result from cumulated trauma and repetitive stress (Yang, Tibbetts, Covassin, Cheng, Nayar, & Heiden, 2012). As a result, eighty percent of all types of running disorders are overuse injuries due to the repetitive stresses applied to the lower extremities (Yang et al., 2012; Van der Worp et al., 2015). To minimize or avoid the risk of these overuse injuries, runners, and more specifically athletes, have to find a way to train without adding unwanted stress to their bodies, while still gaining the positive adaptations of running.

Stress being applied to the lower extremity muscles, tendons, and bones does not always result in a negative effect on running. A certain level of stress is required in order for our physiological systems and structures to positively adapt to the activity and improve in its capacity. In addition to improving the structural functionality of the lower extremities, runners also train to improve their cardiovascular capacity. Cardiovascular training is capable of enhancing functions of the cardiorespiratory system and oxidative capacity of skeletal muscle (Paavolainen, Hakkinen, Hamalaien & Rusko, 1999). In order to obtain the physiological adaptations associated with training, while keeping the possibility of an injury low, continuous stress and stimuli below the mechanical limits of a specific structure being worked must be applied (Kannus, Jozsa, Natri, & Jarvinen, 1997). One method utilized in many rehabilitation and training settings used to avoid excessive forces associated with running has been the use of body-weight support (Grabowski & Kram, 2008).

Running or walking with partial body-weight support has quickly become increasingly popular in injury prevention and rehabilitation. Even though multiple modalities providing body-weight support exist, including the harness system and deep water running, a more recent technology was developed which utilizes air pressure to support the lower extremities during treadmill exercise. The AlterG treadmill (AlterG® 2005, Fremont, CA) uses Differential Air Pressure technology (DAP), which was developed by NASA, within a sealed chamber around the subject to alter their weight while walking or running (Figueroa, Manning, & Escamilla, 2011). The chamber calibrates to equate to air pressure to the individual’s body-weight. After calibration, the treadmill can then increase the air pressure inside the device to decrease bodyweight by 80%.

An advantage to utilizing the AlterG compared to the other modalities is that it allows the trainers and rehabilitation specialists to modify the air pressure in the chamber of the treadmill much quicker and efficiently, providing a range from 20% to 100% of the individual’s body-weight. The AlterG also allows for improved mobility, strength, and safety for the individual while improving overall functional capacity related to strength, power, and endurance (Patil, Steklov, Bugbee, Goldberg, Colwell Jr, & D’Lima, 2012)

In order for these benefits to be effective on a greater scale and not only regarding special populations, an array of physiological variables needs to be assessed to determine whether or not a similar cardiopulmonary adaption can be achieved in a healthy population. A study performed by Figueroa et al., 2011 altered the weight of individuals, up to 20%, and observed certain performance variables including VO_{2max} and HR_{max}, however no significant increases or decreases were observed in these two primary measures, however they did observe a significant change in ratings of perceived exertion in the male group at 80% of bodyweight. Physiological measures that are most commonly studied in exercise physiology, and more specifically with athletes include maximal oxygen consumption (VO_{2max}), maximum heart rate (HR_{max}), and ventilatory thresholds (VT). Relationships between all these variables and overall running performance have been determined in typical exercise protocols, however they have rarely been studied while reducing a percentage of an individual's body-weight. Specifically, there is minimal research that has investigated the relationship between these physiological variables while using a lower body positive pressure treadmill (LBPPT – AlterG).

The value of oxygen uptake is one of the few primary factors assessed in the needs of cardiovascular conditioning as it represents the capacity of the muscle cells to use oxygen during dynamic work (Bassett & Howley 2000). The determinants of oxygen uptake, which influence the body's ability to take in and utilize oxygen, depend on several physiological processes such as diffusion of oxygen from lung alveoli to pulmonary capillary blood to the muscle and cardiac output. This, and other factors including HR_{max} and assessing the ventilation at different percentages of body-weight support, needs to be analyzed in order to find reasoning to believe that cardiovascular conditioning can improve with a similar or potentially greater degree of a physiological stimulus that may lead to improvements in performance while treating or decreasing the risk of injury.

Statement of Purpose

The purpose of this research experiment was to measure absolute VO_{2max}, HR_{max}, ventilatory thresholds 1 and 2 (VT_1 & VT_2), ratings of perceived exertion (RPE), test performance, O_2 pulse, and maximal oxygen saturations at different percentages of body-weight supported running on the AlterG treadmill to determine if any maximal cardiopulmonary changes may occur.

Significance of the Thesis

It is universally accepted that there is a physiological upper limit to an individual body's ability to consume oxygen. However, this theory has been seldom investigated at a variation of different body-weights of an individual. Limited research has also considered different physiological measures at different percentages of body-weights or utilizing body-weight support. Therefore, this study was designed to determine if an adequate amount of cardiovascular and metabolic stress can be applied during unweighted running to result in the same or greater physiological adaptation, with the goal of allowing trainers, along with endurance athletes, additional modalities of training to treat or prevent injury.

Limitations

The study was limited by:

1. The participants filling out the health questionnaire honestly.
2. The participants filling out the training history accurately.
3. The amount of training done previous to the study.
4. There was no dietary intake control.

Delimitations

The following were delimitations of the study:

1. All participants were highly trained athletes with a one-year minimum of competitive experience.
2. A requirement of being on a current endurance training program.
3. All participants were familiarized with the AlterG treadmill.
4. All participants were given the option to perform any specific warm-up as per their usual routine prior to competition/training
5. Certain procedures were replicated from previous research that have shown repeatable results.
6. All participants were blinded to the percent at which they are exercising.
7. All participants were blinded to the data until completion of the study.
8. A Latin Squares counter balanced design was used to determine order of tests.

Assumptions

The following were assumptions made during the study:

1. The subjects understood and followed all directions given to them.
2. The subjects gave a maximal effort during each of the tests.
3. The VO_{2max} represents the participants' maximal effort
4. Maximal performance was limited by physiological capacity and not a previous or existing injury or medical condition

Definition of Terms

AlterG: a treadmill that uses air-pressure technology in a chamber, developed by NASA, to lower a percentage of body-weight of an individual

BW: body-weight - an individual's total mass

GXT: graded exercise test - an incremental exercise test done on a treadmill or cycle ergometer with increasing speed or grade with pre-determined stages

HR: heart rate - the number of beats per minute if the rate remained constant throughout

HR_{max}: the highest value of heart rate achieved at the point of maximal exertion

Lactate: a glycolytic intermediate derived from the reduction of pyruvate

Maximal Oxygen Consumption (VO_{2max}): the greatest rate of oxygen utilization (VO_2) by the working musculature measured during an incremental exercise test

RPE: ratings of perceived exertion self-reported while exercising on a scale ranging from 6 to 20 (self-reported)

SaO_2: concentration of oxygen that is dissolved or carried by hemoglobin in a given medium of blood proportionate to the maximal concentration; expressed as a percent (%)

Ventilatory Threshold: the point at which a non-linear deviation of ventilation (V_E/VO_2) occurs during an exercise bout without an increase in V_E/VCO_2; a noninvasive marker for lactate threshold

Hypotheses

It was hypothesized that:

1. There will be no significant differences in absolute maximal oxygen consumption (VO_{2max}) at all three levels of body-weights and between gender.
2. There will be no significant differences in HR_{max} between all three levels of body-weights and between gender.
3. There will be no significant difference in the first ventilatory threshold (VT_1) at the percent of HR_{max} between all three levels of body-weights and between gender.
4. There will be no significant difference in the second ventilatory threshold (VT_2) at the percent of HR_{max} between all three levels of body-weights and between gender.
5. There will be no significant difference in the first ventilatory threshold (VT_1) at HR (bpm) between all three levels of body-weights and between gender.
6. There will be no significant difference in the second ventilatory threshold (VT_2) at HR (bpm) between all three levels of body-weights and between gender.

7. There will be no significant differences in RPE between all three levels of body-weights and between gender.
8. There will be no significant differences in maximal SaO_2 between all three levels of body-weights and between gender.
9. There will be no significant differences in test performance (min) between all three levels of body-weights and between gender.
10. There will be no significant differences in O_2 pulse between all three levels of body-weights and between gender.

Chapter 2

REVIEW OF LITERATURE

Aerobic exercise, such as jogging, is an activity many people, including athletes, utilize to improve cardiovascular function and expend calories to improve overall performance while also decreasing body fat percentage and weight (Figueroa et al., 2011). Many previous studies have shown that when individuals walk or jog at normal body-weights, metabolic demand increases as velocity increases (Grabowski, 2010). The higher metabolic demand of walking fast and running is likely attributed to increases in stride frequency, increases in overall mechanical power, and generation of greater ground reaction forces over the shorter periods of the contact with the ground (Griffin, Roberts, & Kram, 2003).

Grabowski & Kram (2004) manipulated weight and mass in a stimulated reduced gravity environment and found that net metabolic rates decreased moderately when reducing individuals' body-weight by 25%. However, net metabolic rates increased significantly when the individuals were loaded while manipulating weight and mass while they exercised (Grabowski & Kram, 2004).

Overuse Injury

An overuse running injury is any type of damage to the musculoskeletal system resulting from fatigue over a duration of time beyond the capabilities of the structures of the body that have been continuously stressed (Hreljac & Ferber, 2006). Many forms of overuse injuries exist such as stress fractures, ligament tears, plantar fasciitis, and tendonitis. These can occur when a large number of repetitive forces in small magnitude are applied to a specific structure on the body such a muscle or a tendon (Yang et al., 2012). Running is one of the most common activities that give rise to overuse injuries and the predominant locations of a majority of these injuries include the knee and lower back (Van der Worp et al., 2015).

However, stress on a specific structure of the body is not necessarily a detrimental effect. Positive adaptations, such as remodeling, can occur when repetitive stresses are applied below the tensile limit of a muscle or tendon (Kannus et al., 1997). An adequate time period is also crucial for proper recovery (Kannus et al., 1997). This force, also known as the factor of loading, is essential when it comes to the maintenance of the different mechanical aspects of the body that help improve functioning of a variety of movements (Costill, Coyle, Fink, Lesmes, & Witzmann, 1979).

Over seventy-five percent of all running injuries occur below or at the point of the knees (Hreljac & Ferber, 2006). Frequency, intensity, distances, environmental conditions and runner’s shoes can all contribute to overuse injuries. More specifically, increases in intensity of the training program, surface and shoes, and excessive running distances all have been shown to lead to different types of running injuries (Marti, Vader, Minder, & Abelin, 1988). Forces applied to the lower extremities have been shown to vary in magnitude by over two times one’s body-weight when maximally running and can last for more than 20 milliseconds (Cavanagh & Lafortune, 1980). Therefore, reducing forces applied to the lower extremity during running can greatly reduce the risk of injury however, the effects on performance have still yet to be thoroughly investigated.

Body-weight Support

Harness systems have become a popular modality among different clinical populations such as individuals with lower extremity dysfunction, stroke and even athletes that have suffered bone and tissue impairment (Hesse, Werner, Von Frankenberg, Kappel, Kriker & Käding, 2003; Kelsey & Tyson, 1994). Studies have found that running at 50% and sometimes even 75% of body-weight led to a decrease in net metabolic rate by 38 ± 2.1% and 19 ± 1.7% (Teunissen, Grabowski, & Kram, 2007). These harness systems provide a sense of safety among vulnerable populations who are unable to achieve static balance with their body-weight and exercise without the risk of further injury (Visintin, Barbeau, Korner-Bitensky, & Mayo, 1998). The harness suspension systems are beneficial due to the vertical force that can be applied to the individual. However, it may not be applicable to extended training or rehabilitation use due to discomfort caused by the obstructed circulation (Grabowski, 2010), suggesting a need for better systems for reducing body-weight while maintaining comfort.

Deep water exercise can involve running or walking with or without a treadmill in a pool or enclosed area and it has been observed to provide increased levels of comfort (Alkurdi, Paul, Sadowski, & Dolny, 2010). The buoyant forces of the water assist in reducing the vertical ground reaction forces experienced on land (Hinman, Heywood, &

Day, 2007), similar to harness systems. However, deep water running may not be the most effective body-weight reducing modality for training purposes due to the viscous drag that is associated with the water. Drag in water can cause different muscles to be used during the exercise period and result in a variety of different joint ranges of motion. The drag forces experienced during exercise in water act in opposition to the movement being performed such as forward running or walking, and in turn can cause significant changes in velocity, joint kinetics, joint kinematics, gait and overall muscle activity (Grabowski, 2010). This could then lead to a lesser chance of stimulating a cross-training stimulus and allowing for any significant improvements in performance (Shono, Fujshima, Hotta, Ogaki, & Ueda, 2001).

The AlterG treadmill developed by NASA uses differential air pressure technology to reduce an individual’s body-weight up to 80% (Figueroa et al., 2011). The major goal of these types of treadmills is to maintain or improve aerobic capacity while limiting the stresses induced by the varying ground reaction forces (Grabowski, 2010). Research has shown that exercising on these types of treadmills can lower the metabolic cost as body-weight is brought down. Therefore, this in turn would lead to lower consumption of oxygen at the same speed and grade (Figueroa et al., 2011; Grabowski, 2010; Grabowski & Kram, 2008).

Utilizing a device that can mimic the effects of a Lower Body Positive Pressure treadmill, such as the AlterG, seen in deep water exercise, can eliminate the effects of drag forces to the legs (Cutuk, Groppo, Quigley, White, Pedowitz, & Hargens, 2006).

Lower body positive pressure devices may also be advantageous as they allow kinematic gait patterns similar to those to normal weight ground walking. These devices are also comfortable as they do not obstruct circulation similar to the harness system. In addition, they can be used for long periods of time, and can be adjusted to fit multiple body types (Cutuk et al. 2006).

Due to the decrease in the metabolic cost of exercise with decreasing body-weight on a lower body positive pressure treadmill, individuals must increase their speed to induce training adaptations. Increasing the speed not only helps increase aerobic capacity during running at lower body-weights but also increases muscle activity (Figueroa et al., 2011). However, increasing exercising speeds and reducing body-weight is not proportionate to metabolic cost. For instance, running at 60% of one’s body-weight is not proportionate to the relative cost of running at 80% of one’s body-weight (Teunissen et al., 2007). The lower body positive pressure treadmill has been previously utilized as an exercise tool to maintain as well as improve aerobic capacity while limiting the stresses placed on the body due to the ground reaction forces (Grabowski, 2010). Grabowski, 2010 observed that during walking, an assistive force in the horizontal direction of only 10% could reduce the metabolic power by as much as 50%. While a lateral stabilizing support of approximately 10% could reduce metabolic power by about 4% (Grabowski, 2010). The percentage of metabolic power was also estimated for body-weight support and it was observed that approximately 56%, 54%, and 51% at 1.00, 1.25, and 1.50 m/s, however these percentages were not significantly different (Grabowski, 2010).

The treadmill is used by all populations, especially those with a disability, or chronic injury, that might cause severe limitations and difficulty while exercising (Hoffman & Donaghe, 2011). This would support the notion that lower body positive pressure systems, such as AlterG, may be an ideal system to reduce overuse injuries, and provide aerobic benefits, while maintaining running mechanics and comfort that limit other body-weight support systems or under water running.

Body Compression and Venous Return

The use of lower-body compression such as tights have gained huge popularity among athletes of all levels (Miyamoto & Kawakami, 2014). One study had observed that the use of different forms of compression during exercise can improve running economy, tissue oxygenation, and venous return (Miyamoto & Kawakami, 2014). Varying amounts of pressure have also been applied to athletes, utilizing compression gear and determining whether or not there was a difference in performance (Mizuno, Arai, Todoko, Yamada, & Goto, 2017). The results showed that jump height was significantly higher following the greatest amount of pressure applied to the athletes compared to the lower pressures and control group (Mizuno et al., 2017). Another study had also found that the factor of pressure applied to the lower extremities was able to reduce the development of fatigue of the exercising muscles during submaximal running in healthy active individuals (Miyamoto & Kawakami, 2014).

A theoretical mechanism proposing how the benefits of compression and pressure to the lower extremities arise include the effect on venous return (Ibegbuna, Delis, Nicolaides, & Aina, 2003). The compression gear applies a direct pressure on the underlying tissues of the lower extremities which may reduce the transmural pressure of the arterioles, causing them to dilate and subsequently increase blood flow (Driller & Halson, 2014). Compression gear also may provide enough pressure to result in redistribution of blood from the periphery to the deep venous system, further assisting in an increase in the return of blood flow to the heart (Partsch & Mosti, 2008). The promotion of venous return during and following exercise is thought to be an effective method in further removing metabolic waste and therefore may enhance performance and recovery (Davies, Thompson, & Cooper, 2009). However, further research on the effects of pressure and performance remains equivocal.

Maximal Oxygen Consumption and Protocol Selection

Maximal oxygen uptake (VO_{2max}) has been the most common used measure for the assessment of physiological capacity over the years, and, providing that the defined criteria for this are attained, it remains one of the most objective assessments of physical fitness (Davies, Daggett, Jakeman, & Mulhall, 1984). Even though VO_{2max} does not predict endurance performance, it does provide a measure of the upper limit capabilities of distance running performance (Bassett & Howley, 2000). Oxygen consumption while exercising increases linearly over time with increases in work rate up to a maximal level. Many physiological variables, both central and peripheral, can influence and limit VO_{2max}

such as rates of pulmonary diffusion, specific skeletal muscle characteristics, oxygen-carrying capacity of the blood, and maximal cardiac output (Bassett & Howley, 2000).

Various predictive tests have been developed to determine VO_{2max} as direct measurements of the maximal oxygen consumption but were too expensive in terms of time and cost for application in clinical settings. Some of these tests include measures related to performance such as walking or running in a given time, performing a multistage progressive shuttle test (MST) with increases in speed, and the measurement of heart rate during given workloads and extrapolating to a predictive maximum heart rate to estimate VO_{2max} (Grant, Corbett, Amjad, Wilson, & Aitchison, 1995). However, since these are only predictive measures, the most accurate method to attain true maximal consumption is by directly measuring an individual’s oxygen uptake during progressive increases in exercise intensity (Hamlin, Draper, Blackwell, Shearman, & Kimber, 2012).

The closer the stimulation of the specific muscular action involved in an activity, the more objective and valuable the assessment of maximal oxygen consumption becomes (Davies et al., 1984). Therefore, the choice of ergometer used for the testing of VO_{2max} is important and should recruit the specific muscle groups used for the task of interest (i.e. running).

Determining the appropriate protocol for testing can usually be a complex process as multiple protocols have now been developed since the maximal test first began its standardization process. The standard and commonly-used Bruce protocol is performed on a treadmill and includes sudden changes in the speed and elevation which in turn cause a higher oxygen consumption (Bires, Lawson, Wasser, & Raber-Baer, 2013). The design of the Bruce Protocol demands a high amount of exertion and therefore may cause some individuals to prematurely stop exercising before reaching the required 80-85% of their age-predicted maximum heart rate. However, the ramped Bruce protocol provides more modest changes in speed and elevation, which can lead to better individual tolerance (Bires et al. 2013).

There is also debate over whether or not maximal test protocols should be designed specifically for each population compared to using a pre-designed method with limited adjustments. Research has shown when maximal oxygen consumption was assessed and compared using the standard Bruce protocol against a simplified and less restrictive Athlete-led protocol with the same population, there were no substantial differences in maximal oxygen uptake, 47.0±9.1 compared to 46.8±10.7 ml/kg/min, evidenced by correlation coefficients (Hamlin et al. 2012.).

Hamlin et al. (2012) used the Athlete-led protocol by specifying initial speed according to fitness and training status to each athlete tested. This protocol attained a much higher maximal heart rate of 182.2±10.5 compared to 179.7±8.7 bpm with the standard Bruce protocol. It was argued that that the athletes had increased levels of fatigue and discomfort in their legs with the Bruce protocol, which resulted in them reaching exhaustion before maximal heart rate could be achieved. The Athlete-led protocol also took a shorter period of time to complete the test to reach maximal consumption, approximately 23 seconds less than the standard Bruce (Hamlin et al. 2012). These results show that a protocol designed to meet the individualized fitness status exhibit similar VO_{2max} values compared to the standard Bruce and is quicker and simpler and can be a much more useful alternative to traditional protocols to test maximal aerobic fitness.

Cardiovascular Determinants of VO_{2max}

The Fick equation, formulated in 1870, expresses the relationship among cardiac output, oxygen consumption, and the a-vO_2 difference (McArdle, Katch, & Katch, 2015). The equation can be broken down into a few components including cardiac output which is equal to the stroke volume multiplied by the heart rate. And the a-vO_2 difference which is the average difference between oxygen content of arterial and mixed-venous blood (McArdle et al., 2015). Putting together these components by multiplying the cardiac output by the a-vO_2 difference gives us an indirect measure of the VO_2.

The ability for oxygen however, to be extracted from the blood is highly dependent on the diffusion limitations of the skeletal muscle. Larger densities of the capillary networks in the skeletal muscles help facilitate oxygen exchange between the muscle and oxygenated blood by reducing the distances of diffusion and providing a larger surface area for the exchange of gasses (Bassett & Howley, 2000). Oxygen uptake is also dependent on the oxidative enzyme activity of the mitochondria such that a greater density of mitochondria in the muscle can lead to a greater extraction of oxygen (Bassett

& Howley, 2000). As seen in well-trained individuals, the densities of mitochondria and capillaries are near max volumes, thus allowing the muscles performing work to extract and utilize a majority of the oxygen available (Bassett & Howley, 2000).

One study had also shown that when untrained individuals were provided with extra oxygen, their VO_{2max} was not affected. However, when oxygen was removed in small quantities, the VO_{2max} still remained nearly the same (Wagner, 2000). This supports that untrained individuals cannot fully extract and utilize all the oxygen available to them in the bloodstream. However, the ability for greater oxygen extraction in trained individuals only accounts for minor increases in VO_{2max} (Wagner, 2000; Bassett & Howley, 2000).

The transport of oxygen in the body is determined by the cardiac output, which is the rate of blood flow resulting from an individual's heart rate and stroke volume. Studies have shown that trained individuals have a significantly higher maximal cardiac output than most sedentary and untrained individuals. Increases in VO_{2max} with periods of training are mostly due to increases in the maximal cardiac output, more importantly by greater increases in stroke volume (Bassett & Howley, 2000).

Ventilatory Threshold

The term anaerobic threshold (AT) is considered the transition from a predominately oxidative to an anaerobic pathway (Wasserman & McIlroy, 1964). One study had revealed high correlations between AT, endurance performance, quick changes in respiratory gas exchange (ventilatory threshold, VT), and fatigue (Santos & Giannella-Neto 2004). VT has also been shown to be a valid measure of the performance threshold (PT) (Amann, Subudhi, Walker, Eisenman, Shultz, & Foster, 2004).

There is extensive literature addressing the metabolic relationship between the ventilatory equivalent of oxygen method (V_E/VO_2) and the V-slope method of identifying VT, both of which are based on different physiological mechanisms which may be affected differently over time (Amann et al. 2004). The V-slope (VO_2 vs VCO_2) method is greatly dependent on the proton-buffering capability of the bicarbonate system, while the V_E/VO_2 method places a greater emphasis on the ventilatory responses to exercise (Amann et al. 2004).

Studies that have developed training programs that utilize work rates and intensities at their ventilatory thresholds have found improvements in exercise capacity (Belli et al., 2011). These types of studies also led to a higher VO_{2peak} and $HR_{peak.}$ In other studies, threshold based exercise intensity prescriptions elicited greater improvements in VO_{2max} and helped attenuate the individual variation in VO_{2max} training responses when compared to relative percent exercise training (Wolpern, Burgos, Janot, & Dalleck, 2015). These intensities and workloads based of the thresholds are important to consider as this study analyzed how lowering a percentage of body-weight could potentially shift the threshold curves. This shift could then allow for a similar intensity or workload during exercise, while treating or reducing the risk of injury and achieving a similar cardiopulmonary adaptation.

Conclusion

In summary, people run as a form of exercise to improve cardiovascular functions, while endurance athletes use running to improve their overall maximal capacity. Lower body positive pressure systems, such as AlterG, may be the most appropriate for athletic populations as it presents the least number of disadvantages when exercising. Studies have investigated training on bodyweight support in clinical populations such as individuals with stroke and musculoskeletal injuries, but there have been very few studies looking at how this type of device can benefit healthy populations. Therefore, research is needed to examine the effects of decreasing a percentage of a healthy individual's body-weight while exercising and observe changes to sustaining a maximal load while placing less stress on the body while exercising.

Chapter 3

METHODOLOGY

The purpose of this study was to measure absolute maximal oxygen consumption (VO_{2max}), maximal heart rate (HR_{max}), ratings of perceived exertion (RPE), O_2 pulse, ventilatory thresholds 1 and 2 (VT_1 & VT_2) at a percent of HR_{max} and beats per minute, test performance, and maximal oxygen saturations while exercising when an individual reduces their body weight on a LBPPT (AlterG). Each participant performed three graded exercise tests (GXT) using a set treadmill protocol on the AlterG in the laboratory, each separated by at least a week using a Latin Squares counter balanced research design to determine test order. An evaluation of VO_{2max} and HR_{max} along with other performance variables and percent body weight took place in the laboratory as limited research had evaluated the relationship between these variables. All physiological variables were measured and evaluated in a controlled laboratory setting.

Subjects

Twelve total participants, six males and six females, were recruited for the study. Participant descriptive data can be found in table 3.1 and no significant differences were found between males and females in their total weights. Participants were recruited from St Mary's College of California recreational and competitive teams, Sacramento State University recreational and competitive teams, Sacramento area running clubs, and independent sources. All participants were recruited through e-mail and word of mouth.

Participants were to possess current or previous competitive training experience and on a current training program. Participants were also required to not have had any current or previous musculoskeletal injuries within the past six months.

Table 3.1. Descriptive Statistics of Participants

Group	Age (years)	Weight (kg)	Height (m)
Total Group (n=12)	23.1 ± 1.8	67.75 ± 7.2	1.65 ± 0.13
Males (n=6)	22.3 ± 1.5	69.91 ± 3.5	1.70 ± 0.19
Females (n=6)	24.0 ± 1.9	65.60 ± 9.5	1.59 ± 0.17

Health History and Screening

Prior to testing, all prospective participants were asked to complete a health history questionnaire designed by the researchers along with an informed consent form to determine eligibility in the study. The experimental procedures, potential risks, and any benefits involved with the current study were explained in detail to each prospective participant and any questions they may have had were answered to their satisfaction. Participants that were screened as high risk for cardiovascular disease and sudden cardiac issues were excluded from the study. All prospective participants that met the threshold for participating in the study and accepted the offer to participate were assigned participant numbers to assure anonymity. Training mileage and descriptions were self-reported. Health history questionnaire and informed consent forms are included in appendices.

Experimental Design

All participants in the study engaged in exercise testing at Saint Mary's College in Moraga, CA. Participants arrived at the training room for exercise testing on three separate occasions, each of which was separated by at least one week. Participants' height and weight data were taken prior to each of the sessions. Environmental conditions such as barometric pressure, room temperature, and relative humidity of the testing room were measured on each of the testing days. Percent BW at which each participant exercised at was pre-determined and designed in a Latin Square pattern.

All participants completed a series of graded exercise tests (GXT) on the LBPPT (AlterG) and adhered to all of the required testing procedures. Participants were instructed to prepare for the testing day as they would prior to any competition day, including following any specific personal methods they have regarding hydration, diet, and rest. This information was recorded and kept constant throughout all three tests. Before the start of any data collection and exercise testing, all of the participants were familiarized with the equipment and testing procedure. They were all also familiarized with the treadmill prior to their first GXT by attaching them to the treadmill and allowing them to walk at a moderate speed on the treadmill and slowly increasing the speed by 0.5 mph to a comfortable running speed and giving them time to adjust to the treadmill.

Procedure

On the first day of data collection, participants arrived at the laboratory at St Mary’s College with appropriate running footwear and attire. The percentage at which the participant would be testing each visit was pre-determined. A heart rate monitor (Polar) was placed on each of the participants’ chest prior to their warm-up to attain a resting heart rate value prior to the testing. Prior to the exercise test, participants were instructed to perform a warm-up. They were all given the option to perform a specific warm-up of their own preference and usual routine and this was recorded and kept constant throughout all three GXT’s. Heart rate was monitored continuously every 15 seconds during rest and the GXT through telemetry. Heart rate was recorded at a 15-second average of each stage on the metabolic cart and at test termination during the exercise test to determine each participants’ HR_{max}.

Prior to each GXT and while the participant warmed up, the pneumotach of the metabolic cart was calibrated at a variety of different flow rates with a 3-liter calibration syringe (Hans Rudolph Inc., Kansas City, MO, USA) to measure expired gas volumes during the GXT. The gas analyzers were also calibrated using gases of known concentrations (16% O_2; 3% CO_2) and measured the concentrations of expired gas during all of the exercise tests (via a one-way valve and mixing chambers). Calibration of the cart was successful if the percent change of the calibration was less than 1.0% from the previous calibration.

Participants then completed a GXT on the LBPPT (AlterG). Each participant was blinded to the percentage at which they were exercising at. Gas exchange measurements and ventilation rates were obtained every 15 seconds during the GXT using the metabolic cart (Parvo Medics). The skirt size for each participant that connected them to the treadmill was recorded and kept constant throughout the entire study. An athlete-led protocol was used for the GXT and the treadmill began at 5.0 mph and 0% grade. The speed increased 0.5 mph every minute and grade by 1% after the second minute until volitional fatigue had occurred. The same GXT protocol was used for all three tests. The first minute of the testing began at rest to ensure that there was not any malfunctions or leaks in the metabolic cart and hoses used. Ratings of perceived exertion (RPE) were recorded at the end of each stage during the GXT using a scale ranging from 6 (no exertion at all) to 20 (maximal exertion). Testing occurred until the subject could no longer maintain the required treadmill speed and grade by grabbing the sides of the treadmill and straddling their legs on the side leg bars indicating they could no longer go on or giving us the cut cue by waving their hand. Once the test had terminated, maximal oxygen saturations were taken using a forehead pulse oximeter probe (Masimo, Irvine, CA, USA).

After test termination, all participants were required to perform an active cool-down by walking on the treadmill for a minimum of 5 minutes at a speed of 2.5 miles per hour and an incline of 0% and allowing them to perform any other cool-down as per their usual routine. After the completion of their cool-down, the participant then scheduled for their next GXT, at least a week apart from the first. All data collected was blinded to the participant until their final GXT was completed or if they had terminated early from the study.

Data Analysis

Absolute maximal oxygen consumption (VO_{2max}) was considered to be the highest absolute value achieved during the GXT using the 15-second averaging calculated on the metabolic cart (Parvo Medics). Maximum heart rate was determined as the highest point of beats per minute corresponding with the VO_{2max}. Ventilatory thresholds (VT_1 and VT_2) were determined by graphing the gas exchange values (y-axis) obtained from the metabolic cart (Parvo Medics) against time of the GXT (x-axis). These time points were then matched with the corresponding heart rates and workloads during the GXT. VT_1 was determined from the first inflection point of a disproportionate increase in pulmonary ventilation to oxygen uptake. VT_2 was determined as the second exponential rise in V_E/VO_2 with a corresponding rise in V_E/VCO_2 (Wasserman et al. 1973). O_2 pulse was calculated at VO_{2max} by taking the absolute value and converting to milliliters and dividing by the HR_{max}.

Statistical Analysis

The experimental data was presented as means and standard deviations. Data were analyzed using SPSS version 25. A three by two mixed-model repeated measures ANOVA was used to compare the main effects of the within-subject differences (BW –

100%, 75%, and 50%) and between-subject differences (gender – male and female). A Bonferroni pairwise comparison was used to identify any significant differences throughout the within-subject effects of BW. If a significant interaction was observed, a Tukey post-hoc analysis was then used. An alpha level of $p < 0.05$ was used to identify any significant statistical differences.

Chapter 4

RESULTS

Descriptive statistics for all participants including age, height, and weight were analyzed and reported in table 3.1. A three by two mixed model repeated measures ANOVA was used to analyze any differences in the within-subject factors (BW) and the between-subject factors (gender). If a significant interaction had occurred, a Tukey post-hoc analysis was used to identify the specific comparison which was significant. All data was reported as averages ± standard deviation for the total group (n=12), males (n=6) and females (n=6).

Absolute VO_{2max} ($L \cdot min^{-1}$)

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD for absolute VO_{2max} can be found in table 4.2. No statistical significance ($p>0.05$) in the within- and between-subject tests was observed in any of the comparisons of %BW between both genders.

Table 4.1. Mean values for absolute VO_{2max} ($L \cdot min^{-1}$) across the 3 levels of BW.

Variable	100%BW	75%BW	50%BW
VO_{2max}	3.98 ± 0.53	3.94 ± 0.54	3.93 ± 0.57
VO_{2max} (male)	4.23 ± 0.51	4.19 ± 0.53	4.16 ± 0.60
VO_{2max} (female)	3.73 ± 0.46	3.68 ± 0.44	3.70 ± 0.47

O_2 Pulse (mL·beat^{-1})

Mauchly’s Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD for O_2 pulse can be found on table 4.2. No statistical significance ($p>0.05$) in the within- and between-subject tests was observed in any of the comparisons of %BW between both genders.

Table 4.2. Mean values of O_2 pulse (mL·beat^{-1}) at VO_{2max} across the 3 levels of BW.

Variable	100%BW	75%BW	50%BW
O_2 Pulse	21.42 ± 2.91	21.45 ± 3.07	21.57 ± 3.18
O_2 Pulse (male)	22.32 ± 3.44	22.43 ± 3.69	22.51 ± 3.86
O_2 Pulse (female)	20.51 ± 2.20	20.50 ± 2.22	20.59 ± 2.28

HR_{max} (beats·min^{-1})

Mauchly’s Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD (expressed as error bars) for HR_{max} can be found on figure 4.1. Tests of within-subject effects (BW) expressed statistical significance ($p<0.05$) with no interaction ($p>0.05$). Tests of between-subject effects (gender) expressed no statistical significance ($p>0.05$). Bonferroni pairwise comparisons expressed significance in the 100-75 %BW comparison and 100-50 %BW comparison. No significance was expressed in the 75-50 %BW comparison ($p>0.05$).

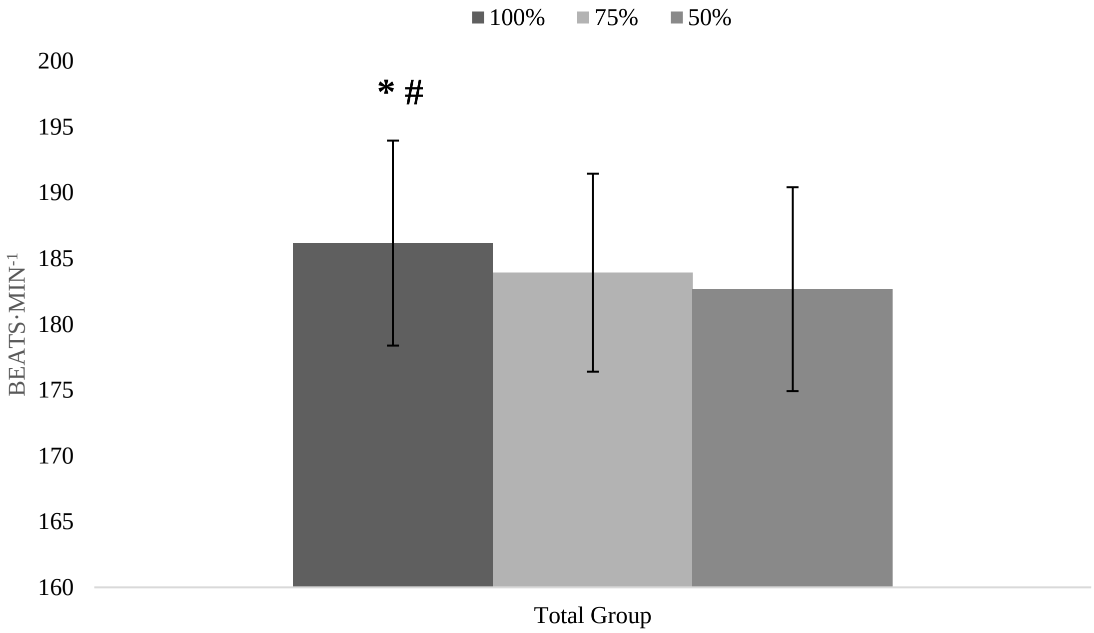


Figure 4.1 Mean values of HR_{max} (beats·min^{-1}) across the 3 levels of BW.
(*) Significantly different ($p<0.05$) between 100%BW and 75%BW.
(#) Significantly different ($p<0.05$) between 100%BW and 50%BW.

Maximum RPE

Mauchly’s Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD (expressed as error bars) for maximum RPE can be found on figure 4.2. Tests of within-subject effects (BW) expressed statistical significance ($p<0.05$) with no interaction ($p>0.05$). Tests of between-subject effects (gender) expressed no statistical significance ($p>0.05$). Bonferroni pairwise comparisons expressed significance in the 100-50 %BW comparison and the 75-50 %BW comparison. No significance was observed in the 100-75 %BW comparison ($p>0.05$).

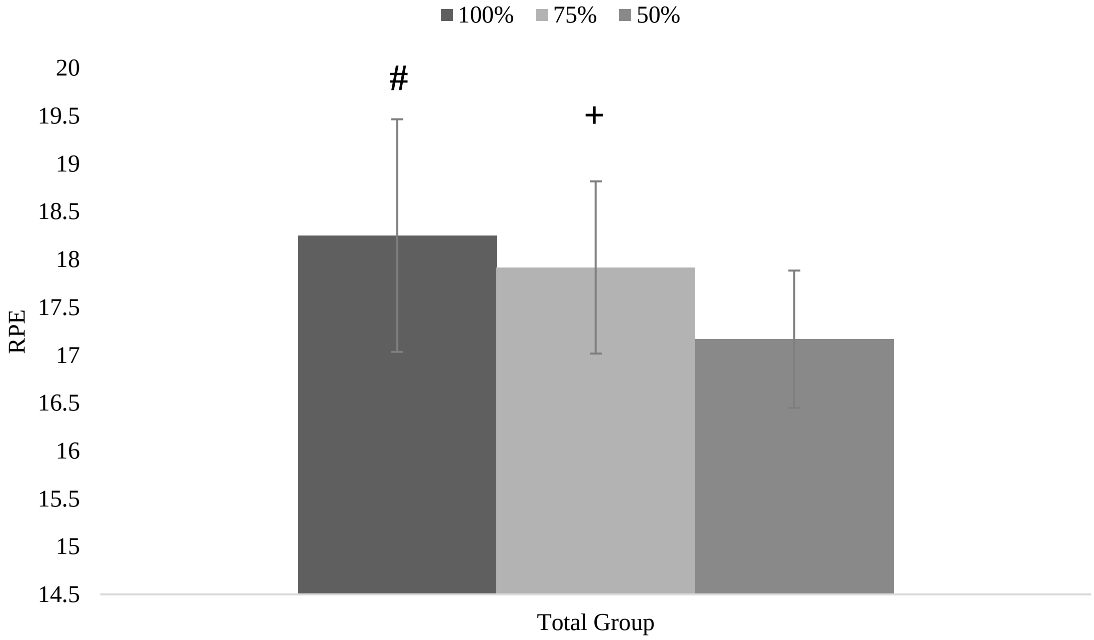


Figure 4.2 Mean values of maximum RPE across the 3 levels of BW.
(#) Significantly different ($p<0.05$) between 100%BW and 50%BW.
(+) Significantly different ($p<0.05$) between 75%BW and 50%BW.

Maximum SaO_2 (%)

Maximum SaO_2 values were only obtained on 10 total participants, 5 males and 5 females. Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD (expressed as error bars) for maximum SaO_2 can be found on figure 4.3. Tests of within-subject effects (BW) expressed statistical significance ($p<0.05$) with no interaction ($p>0.05$). Tests of between-subject effects (gender) expressed no statistical significance ($p>0.05$). Bonferroni pairwise comparisons expressed significance in the 100-75 %BW comparison and the 100-50 %BW comparison. No significance was observed in the 75-50 %BW comparison ($p>0.05$).

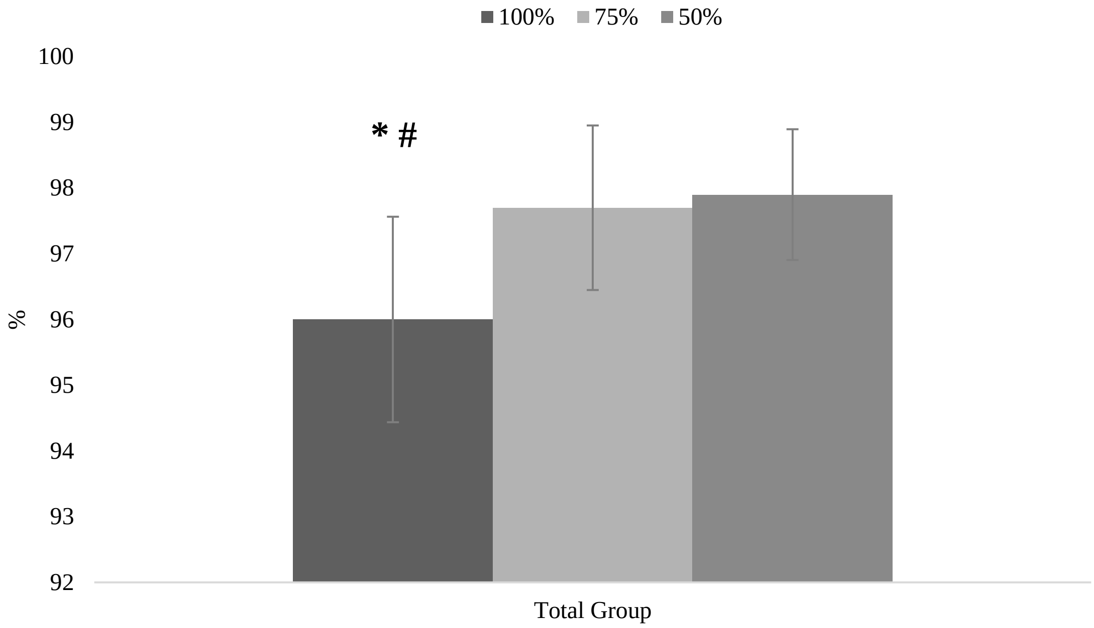


Figure 4.3. Mean values of maximum SaO_2 (%) across the 3 levels of BW.
(*) Significantly different ($p<0.05$) between 100%BW and 75%BW.
(#) Significantly different ($p<0.05$) between 100%BW and 50%BW.

Test Performance (minutes)

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD (expressed as error bars) for test performance can be found in table 4.6. Tests of within-subject effects (BW) expressed statistical significance ($p<0.05$) with no interaction ($p>0.05$). Tests of between-subject effects (gender) expressed significance ($p<0.05$). Bonferroni pairwise comparisons expressed significance in all three %BW comparisons, 100-75, 100-50, and 75-50 ($p<0.05$).

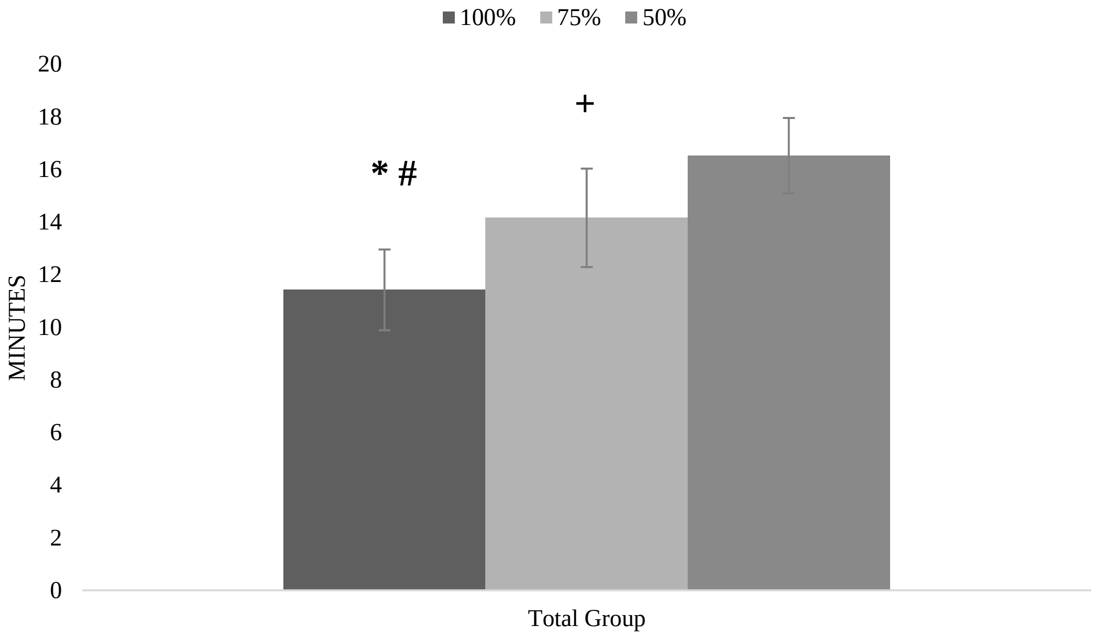


Figure 4.4. Mean values for test performance (min) across the 3 levels of BW.
(*) Significantly different (p<0.05) between 100%BW and 75%BW.
(#) Significantly different (p<0.05) between 100%BW and 50%BW.
(+) Significantly different (p<0.05) between 75%BW and 50%BW.

Ventilatory Threshold 1 (beats·min^{-1})

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD for VT_1 can be found in table 4.3. No statistical significance ($p>0.05$) in the within- and between-subject tests was observed in any of the comparisons of %BW between both genders.

Table 4.3. Mean values for VT_1 (beats·min^{-1}) across the 3 levels of BW.

Variable	100%BW	75%BW	50%BW
VT_1	149 ± 9.18	153 ± 7.79	155 ± 8.31
VT_1 (male)	149 ± 12.6	154 ± 7.75	158 ± 7.46
VT_1 (female)	150 ± 4.94	152 ± 8.44	152 ± 8.43

Ventilatory Threshold 2 (beats·min^{-1})

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD for VT_2 can be found in table 4.4. No statistical significance ($p>0.05$) in the within- and between-subject tests was observed in any of the comparisons of %BW between both genders.

Table 4.4. Mean values for VT_2 (beats·min^{-1}) across the 3 levels of BW.

Variable	100%BW	75%BW	50%BW
VT_2	170 ± 6.86	171 ± 6.99	173 ± 7.91
VT_2 (male)	171 ± 8.77	174 ± 6.91	177 ± 9.33
VT_2 (female)	168 ± 4.75	168 ± 6.04	169 ± 2.73

Ventilatory Threshold 1 (% of HR_{max})

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD (expressed as error bars) for VT_1 can be found on figure 4.5. Tests of within-subject effects (BW) expressed statistical significance ($p<0.05$) with no interaction ($p>0.05$). Tests of between-subject effects (gender) expressed no statistical significance ($p>0.05$). Bonferroni pairwise comparisons expressed significance in 100-75 %BW comparison and the 100-50 %BW comparison. No significance was observed in the 75-50 %BW comparison ($p>0.05$).

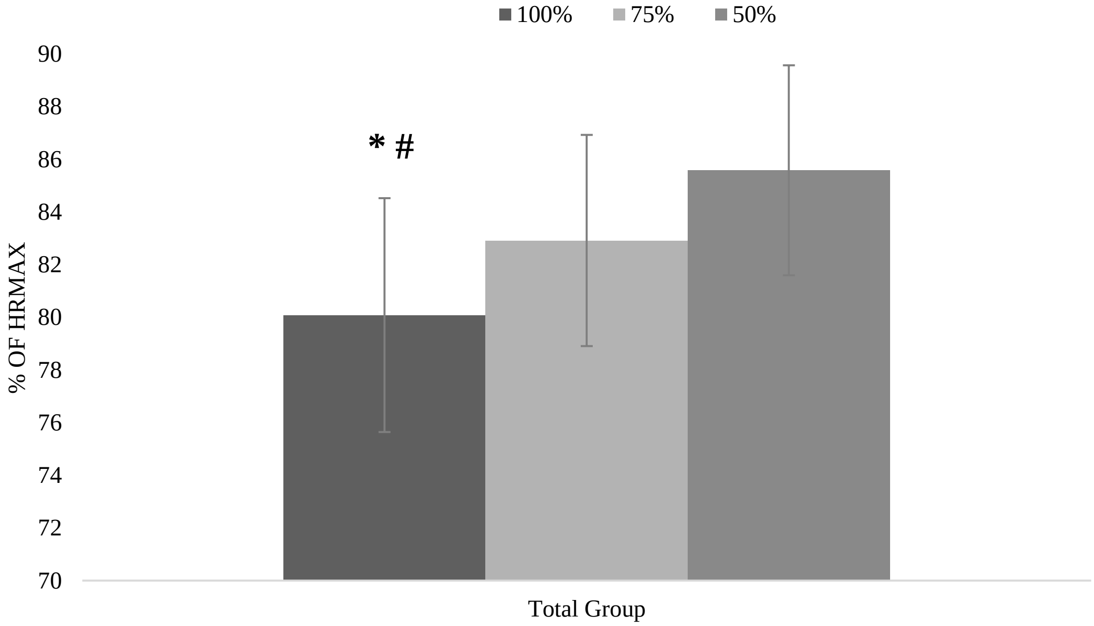


Figure 4.5. Mean values of VT_1 (% of HR_{max}) across the 3 levels of BW.
(*) Significantly different ($p<0.05$) between 100%BW and 75%BW.
(#) Significantly different ($p<0.05$) between 100%BW and 50%BW.

Ventilatory Threshold 2 (% of HR_{max})

Mauchly's Test of Sphericity indicated that the assumption of sphericity had not been violated, $p>0.05$. Mean values ± SD for VT_2 can be found in table 4.5. Tests of within-subject effects (BW) expressed statistical significance ($p<0.05$) with an interaction ($p<0.05$). Tests of between-subject effects (gender) expressed no statistical significance ($p>0.05$). A Tukey post-hoc analysis expressed statistical significance only in the male group ($n=6$) in the 100-50 %BW comparison ($p<0.05$). All other comparisons of %BW expressed no statistical significance ($p>0.05$).

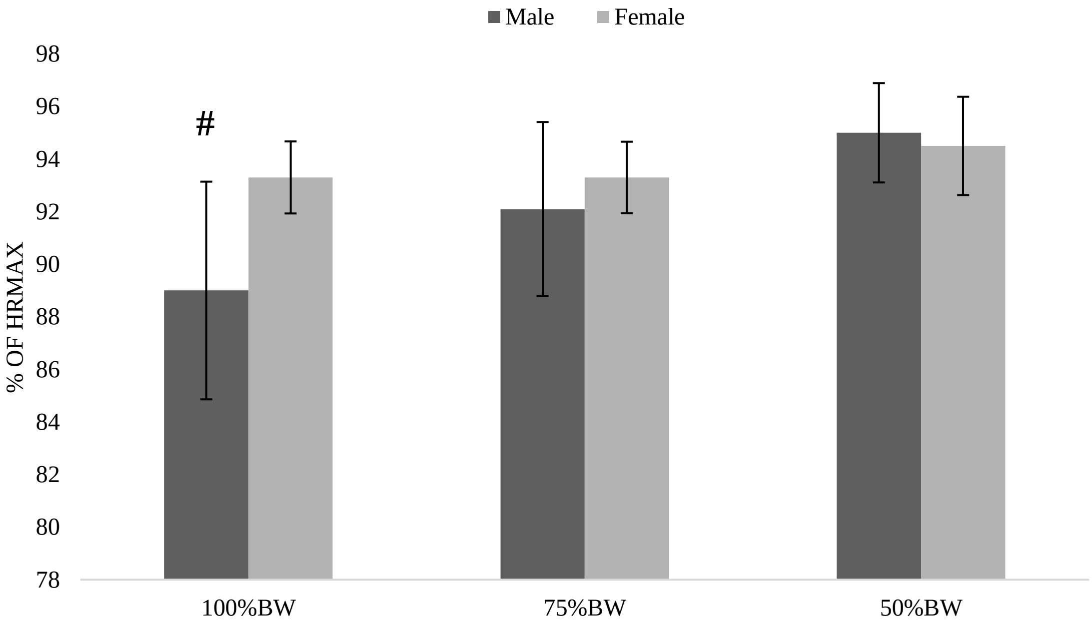


Figure 4.6. Mean values for VT_2 (% of HR_{max}) across the 3 levels of BW.
(#) Significantly different ($p<0.05$) between 100%BW and 50%BW in the male group.

Chapter 5

DISCUSSION

The purpose of this study was to examine the effects of unweighting active individuals on a LBPPT and observing any changes in a range of cardiopulmonary and metabolic variables. Previous studies have performed similar types of experiments and found evidence to support that the metabolic cost decreases with increasing amount of bodyweight support along with a high variability in oxygen uptake, while also reducing the impact of the ground reaction forces applied on the individual while exercising (Figueroa et al., 2011; McNeill, Kline, Heer, & Coast, 2015; Teunissen et al., 2007; Patil et al., 2012). However, few have looked at the possibility of comparing differences in certain performance variables and finding evidence to support developing a training program for healthy individuals on this type of device.

In this study, twelve healthy and active individuals performed a total of three GXT’s on the LBPPT at 100%, 75%, and 50% of their bodyweight. A total of nine maximal and submaximal cardiopulmonary and metabolic measures, including VO_{2max}, $HR_{max,}$ O_2 pulse, maximum SaO_2, maximum RPE, test performance, VT_1 & VT_2, were assessed. Differences in the variables were analyzed between subjects (gender) and within subjects (three percentages of bodyweight). The aim in evaluating these specific variables was to identify any changes that would support the notion that a similar cardiopulmonary adaption from training at 100% of bodyweight may be observed, if healthy individuals were placed on the device to exercise at a given intensity at a lower percent of their bodyweight.

Maximal oxygen consumption (VO_{2max}) was one of the maximal variables assessed in this study. Previous literature has widely recognized that VO_{2max} is limited by the ability of the cardiovascular system to deliver oxygen to the exercising muscles (Bassett & Howley, 2000; Jacobs et al., 2011; Esco, Snarr, Flatt, Leatherwood, & Whittaker, 2013). Therefore, oxygen delivery, not skeletal muscle oxygen extraction, is seen as the primary limiting factor for oxygen uptake. The results of this study found no significant differences in absolute VO_{2max} between and within the twelve subjects, supporting the data from previous literature (Figueroa et al., 2011). Multiple studies utilizing bodyweight support have also found data showing varying values of oxygen uptake at lower percentages of bodyweight at submaximal and maximal intensities. In this study, it was hypothesized that lowering an individual's bodyweight would allow them to sustain a higher workload during the GXT, potentially increasing the venous return compared to the 100% bodyweight trial. This in turn would then have allowed them to potentially increase their oxygen uptake, however we can conclude this may not have been the case as absolute VO_{2max} values remained relatively unchanged and this was confirmed by the examination of the O_2 pulse as well. (men (100%BW): 4.23 ± 0.51, (75%BW): 4.19 ± 0.53, (50%BW): 4.16 ± 0.60; women (100%BW): 3.73 ± 0.46, (75%BW): 3.68 ± 0.44, (50%BW): 3.70 ± 0.47).

Maximal heart rate has also been extensively studied in altered bodyweight testing as well. However, due to researchers analyzing variables separated by stages, true HR_{max} at maximal oxygen uptake was not fully assessed in all participants as some proceeded to further stages compared to others in the study (Figueroa et al., 2011). However, McNeill et al., (2015) observed changes in HR in different percentages of bodyweight and found that at the steady-state lower levels, heart rate was lower in each of the tests of the elite athletes, 171 ± 5.6 (100%BW) & 145 ± 13.7 (80%BW). In this study, we achieved similar results regarding maximal values in that average HR_{max} was lower in each the three levels of bodyweight. Statistical significance was observed in the 100-75 and the 100-50 %BW comparison while no interaction was observed.

This difference may infer that the decline in heart rate observed may have been due to an increase in stroke volume during the GXT. When indirectly calculating oxygen uptake using the Fick equation, we must consider cardiac output (Q) and the a-vO_2 difference to equate VO_2 (McArdle et al., 2015). Cardiac output is equal to stroke volume (SV) multiplied by the heart rate (HR), while the a-vO_2 difference is the oxygen content between the arterial and venous blood, essentially how much oxygen was absorbed by the working muscle. Due to no significant changes observed in the absolute VO_{2max} and average HR_{max} decreasing, we further analyzed the data to see if any changes in oxygen transport or stroke volume may have occurred.

In assessing the a-vO_2 difference in addition to the VO_{2max}, we analyzed the O_2 pulse at the VO_{2max} in each of the participants. The O_2 pulse is the amount of oxygen consumed for every beat of the heart and is a product of how large the stoke volume is, along with the a-vO_2 difference. Calculating this variable gave us a fairly accurate marker for oxygen transport throughout the exercise test if any changes had occurred and was determined by taking the VO_{2max} in milliliters and dividing it by the HR_{max}. No significant increases or decreases were seen in the O_2 pulse in the total group averages throughout the three percentages of bodyweight, as well as no interaction between genders. Due to no changes observed, we can assume that oxygen transport did not significantly change as bodyweight decreased, supporting the rationale as to why no changes in VO_{2max} were observed as well. We can speculate however, that stroke volume may have slightly increased but was compensated for with decreases in the a-vO_2 difference.

Previous research has found that different levels of pressure applied to the lower extremities using different forms of compression gear led to increases in blood oxygen saturations as well as increases in venous return (Miyamoto & Kawakami, 2014; Mizuno et al., 2017). In the LBPPT used in this study, varying amounts of pressure in the sealed chamber were applied to individual’s lower extremities while they exercised to continuously achieve the unweighted effect. This pressure may have acted as the mechanism that increased the stroke volume. Multiple studies have shown that the calf-muscle pump is one of the primary mechanisms that promote venous return from the lower extremities (Recek, 2013; Padberg Jr, Johnston, & Sisto, 2004). Due to the effect of unweighting and external pressure applied from the chamber, this could have led to an increased velocity of flow of the venous return back to the upper extremities and heart causing the proposed increase in stroke volume. This change in venous return or the a-vO_2 difference may also have led to increased maximal SaO_2 values during the 100-75 and 100-50 %BW comparison with no interaction taking place.

Previous literature has considered various submaximal testing variables as accurate indicators of endurance performance (McArdle et al., 2015). Submaximal variables analyzed in the study included VT_1 and VT_2 at the specific heart rate and at a percent of HR_{max}. The threshold during incremental exercise is the point above the aerobic threshold when pulmonary ventilation and carbon dioxide levels, along with lactate concentrations, begin to increase in a disproportionate, or nonlinear manner, in addition to the increases observed in VO_2 (Wasserman et al., 1964; Vucetic, Sentija, Sporis, Trajkovic, & Milanovic, 2014; Ghosh, 2004). In this study, we observed changes in the thresholds as they occurred in a later time point during the GXT, but at nearly the same HR, 149 ± 9.18 at 100%BW to 155 ± 8.31 at 50%BW for VT_1 and 170 ± 6.86 at 100%BW to 173 ± 7.91 at 50%BW for VT_2 for the total group averages.

Furthermore, these thresholds are important to consider because they mark the point at which sustainable metabolism can no longer be maintained during exercise (Vucetic et al., 2014). Sustained metabolism, contributing to the sustained effort of the intensities of exercise from constant energy production, is important at submaximal levels because it provides us the zone in which individuals can train while meeting the demand for oxygen, leading to a longer duration of exercise. If training above the thresholds, fatigue will occur much quicker due to unstable metabolism, such as metabolic acidosis. However, it is known that highly trained individuals can perform at a higher percentage of their VO_{2max} with less or a delayed state of acidosis (Ghosh, 2004; Rosic, Pantovic, Mladenovic, & Rosic, 2007). Because these trained individuals tend to accumulate less lactate than untrained individuals, they are able to achieve a higher submaximal intensity (Ghosh, 2004). This concept provides the importance of the analysis in this study of the thresholds of ventilation. It may potentially allow us a noninvasive, yet accurate, representation of changes in endurance fitness and performance along with physiological adaptations that may arise training at a lower percentage of BW. For this to occur, the data collected from this study must have provided us with evidence that higher intensities can be achieved at a lower body-weight but finding the appropriate zone to train in without reaching the extended threshold that may eventually cancel out any benefits at the greater levels body-weight support.

As mentioned previously, the results of this study showed no statistical significance in the heart rate observed at the onset of the ventilation thresholds. However, significant differences were observed when comparing the percent of the HR_{max} at which the thresholds occurred for the 100-75 and 100-50 %BW comparisons for VT_1 and a significant interaction for VT_2 in the 100-50 %BW comparison for only the males. These thresholds were however prolonged at the lower percentages of BW as workloads got easier to perform at the same intensity compared to the 100% BW trial. This is supported by the decreases in average RPE data, recorded throughout the test, in the 50% and 75%

of BW GXT's. The increased average times of test performance in those trials also provide evidence supporting the increased duration of sustained metabolism during the GXT's at the lower percent of BW.

One benefit to the increased steady state at a higher intensity is that it may provide an extended stimulus to the muscles while exercising. The increased duration of the sustained metabolism during exercise, known as the prolonged steady state, observed on the threshold graphs may have occurred due to the decreased values of CO_2 produced at the same intensity compared to the 100% BW trial. The lower values of CO_2 produced throughout the 50% and 75% BW trial delayed the nonlinear deviation of ventilation during the GXT but occurred at the same heart rate. This indicates an increase in the buffering system or decreases in production of CO_2 during exercise and having the setpoint of when to send signals to the brain to significantly alter breathing during exercise to adjust to the changing levels of pH as quick as possible.

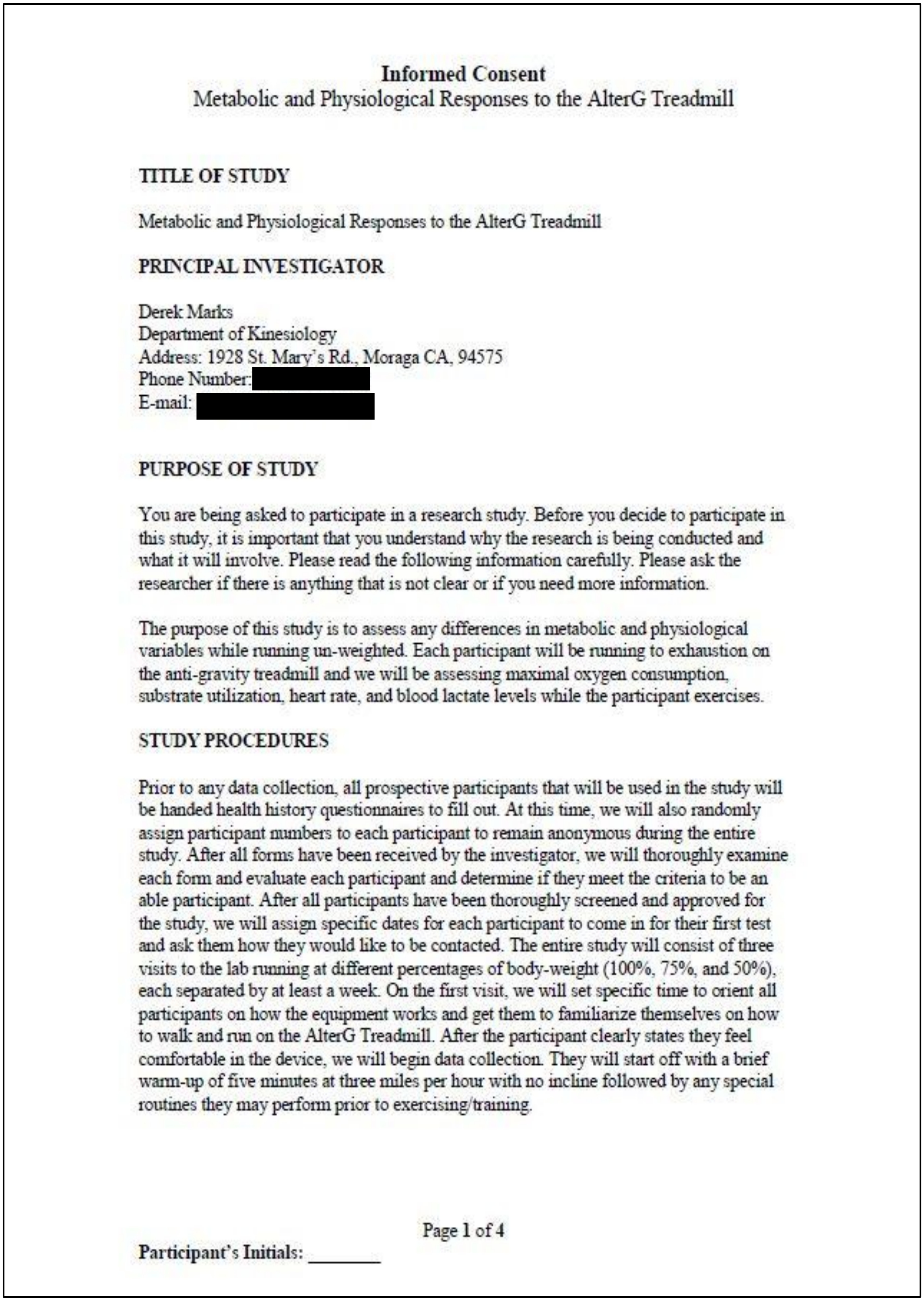
This study was also one of the few that has analyzed these nine performance variables between the two genders, male and female. This lack of data could have led to the possibility of missing out on any interactions that may have taken place by not splitting up the population in other research studies. A significant interaction in this study would have indicated that men and women did not respond to the treatment in a similar manner and could potentially lead to different rates of adaptations, if any were to occur. In this study the only variable to have a significant interaction was VT_2 at the percent of HR_{max} in the male group in the 100-50 %BW comparison. The male group on average experienced a greater drop in HR_{max} compared to the women (5 bpm vs 3 bpm) which could have potentially led to this interaction.

Conclusion

Based on the results from this study, we can conclude that training at a lower percentage of bodyweight can elicit similar cardiopulmonary and metabolic adaptations sustained with training at 100% of bodyweight. Further research is needed to detect the magnitude of these responses by developing a specific training program on the LBPPT among a healthy group of athletes and observing changes in certain performance variables, pre- and post- intervention, such as VO_{2max} over an extended period time. Additional participants among both genders, along with athletes from a range of different athletic backgrounds must also be utilized to provide a better understanding of the extent of who can ultimately benefit from this type of training. Including further analyses during these training programs, such as EMG recordings of the lower extremity muscles may also provide information regarding varying contractional forces on the muscles while pressure is applied from the treadmill and the unweighted effect takes place.

Appendix A

Informed Consent Form



Informed Consent

Metabolic and Physiological Responses to the AlterG Treadmill

TITLE OF STUDY

Metabolic and Physiological Responses to the AlterG Treadmill

PRINCIPAL INVESTIGATOR

Derek Marks
Department of Kinesiology
Address: 1928 St. Mary's Rd., Moraga CA, 94575
Phone Number: [redacted]
E-mail: [redacted]

PURPOSE OF STUDY

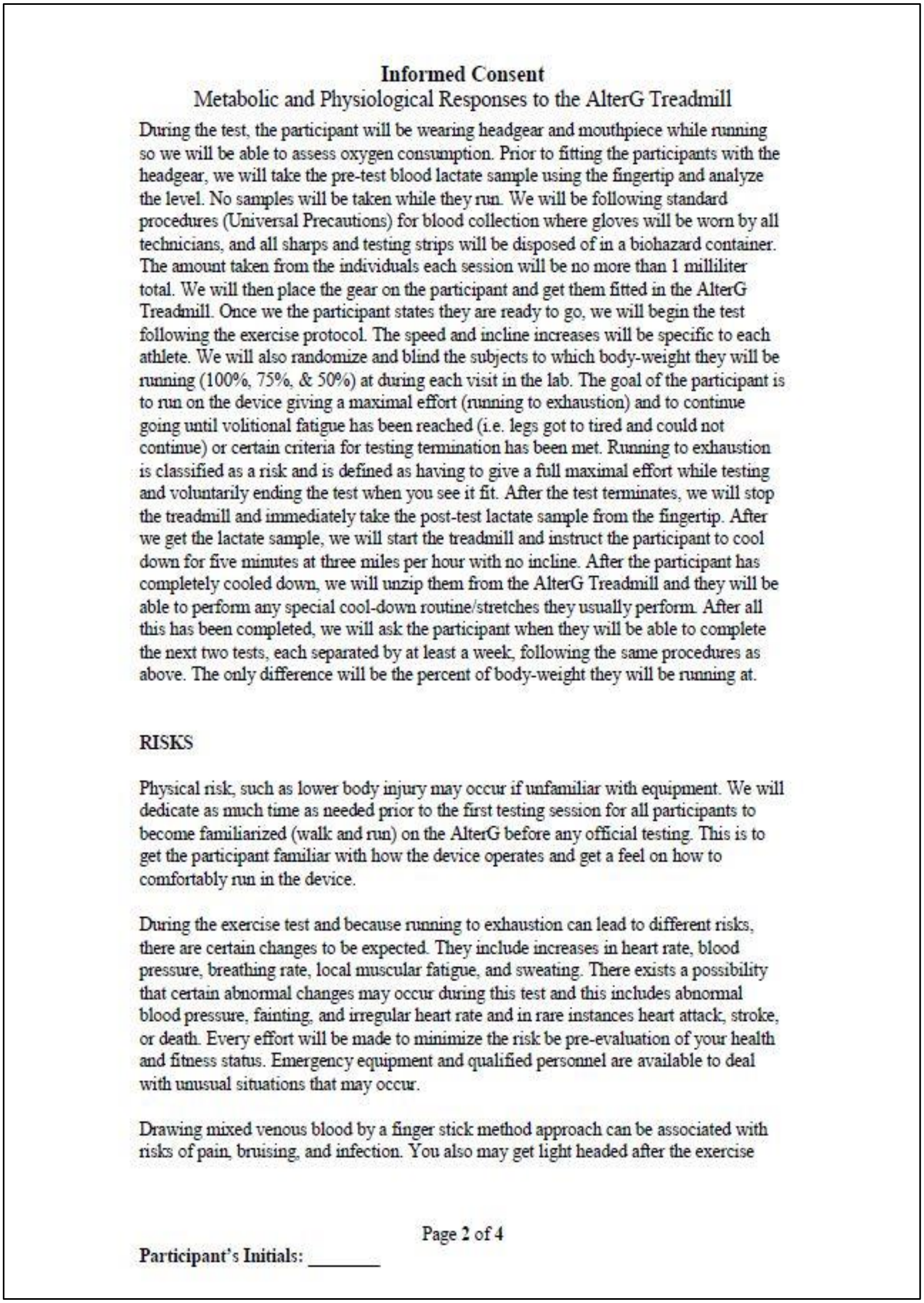
You are being asked to participate in a research study. Before you decide to participate in this study, it is important that you understand why the research is being conducted and what it will involve. Please read the following information carefully. Please ask the researcher if there is anything that is not clear or if you need more information.

The purpose of this study is to assess any differences in metabolic and physiological variables while running un-weighted. Each participant will be running to exhaustion on the anti-gravity treadmill and we will be assessing maximal oxygen consumption, substrate utilization, heart rate, and blood lactate levels while the participant exercises.

STUDY PROCEDURES

Prior to any data collection, all prospective participants that will be used in the study will be handed health history questionnaires to fill out. At this time, we will also randomly assign participant numbers to each participant to remain anonymous during the entire study. After all forms have been received by the investigator, we will thoroughly examine each form and evaluate each participant and determine if they meet the criteria to be an able participant. After all participants have been thoroughly screened and approved for the study, we will assign specific dates for each participant to come in for their first test and ask them how they would like to be contacted. The entire study will consist of three visits to the lab running at different percentages of body-weight (100%, 75%, and 50%), each separated by at least a week. On the first visit, we will set specific time to orient all participants on how the equipment works and get them to familiarize themselves on how to walk and run on the AlterG Treadmill. After the participant clearly states they feel comfortable in the device, we will begin data collection. They will start off with a brief warm-up of five minutes at three miles per hour with no incline followed by any special routines they may perform prior to exercising/training.

Participant's Initials: _______



Informed Consent

Metabolic and Physiological Responses to the AlterG Treadmill

During the test, the participant will be wearing headgear and mouthpiece while running so we will be able to assess oxygen consumption. Prior to fitting the participants with the headgear, we will take the pre-test blood lactate sample using the fingertip and analyze the level. No samples will be taken while they run. We will be following standard procedures (Universal Precautions) for blood collection where gloves will be worn by all technicians, and all sharps and testing strips will be disposed of in a biohazard container. The amount taken from the individuals each session will be no more than 1 milliliter total. We will then place the gear on the participant and get them fitted in the AlterG Treadmill. Once we the participant states they are ready to go, we will begin the test following the exercise protocol. The speed and incline increases will be specific to each athlete. We will also randomize and blind the subjects to which body-weight they will be running (100%, 75%, & 50%) at during each visit in the lab. The goal of the participant is to run on the device giving a maximal effort (running to exhaustion) and to continue going until volitional fatigue has been reached (i.e. legs got to tired and could not continue) or certain criteria for testing termination has been met. Running to exhaustion is classified as a risk and is defined as having to give a full maximal effort while testing and voluntarily ending the test when you see it fit. After the test terminates, we will stop the treadmill and immediately take the post-test lactate sample from the fingertip. After we get the lactate sample, we will start the treadmill and instruct the participant to cool down for five minutes at three miles per hour with no incline. After the participant has completely cooled down, we will unzip them from the AlterG Treadmill and they will be able to perform any special cool-down routine/stretches they usually perform. After all this has been completed, we will ask the participant when they will be able to complete the next two tests, each separated by at least a week, following the same procedures as above. The only difference will be the percent of body-weight they will be running at.

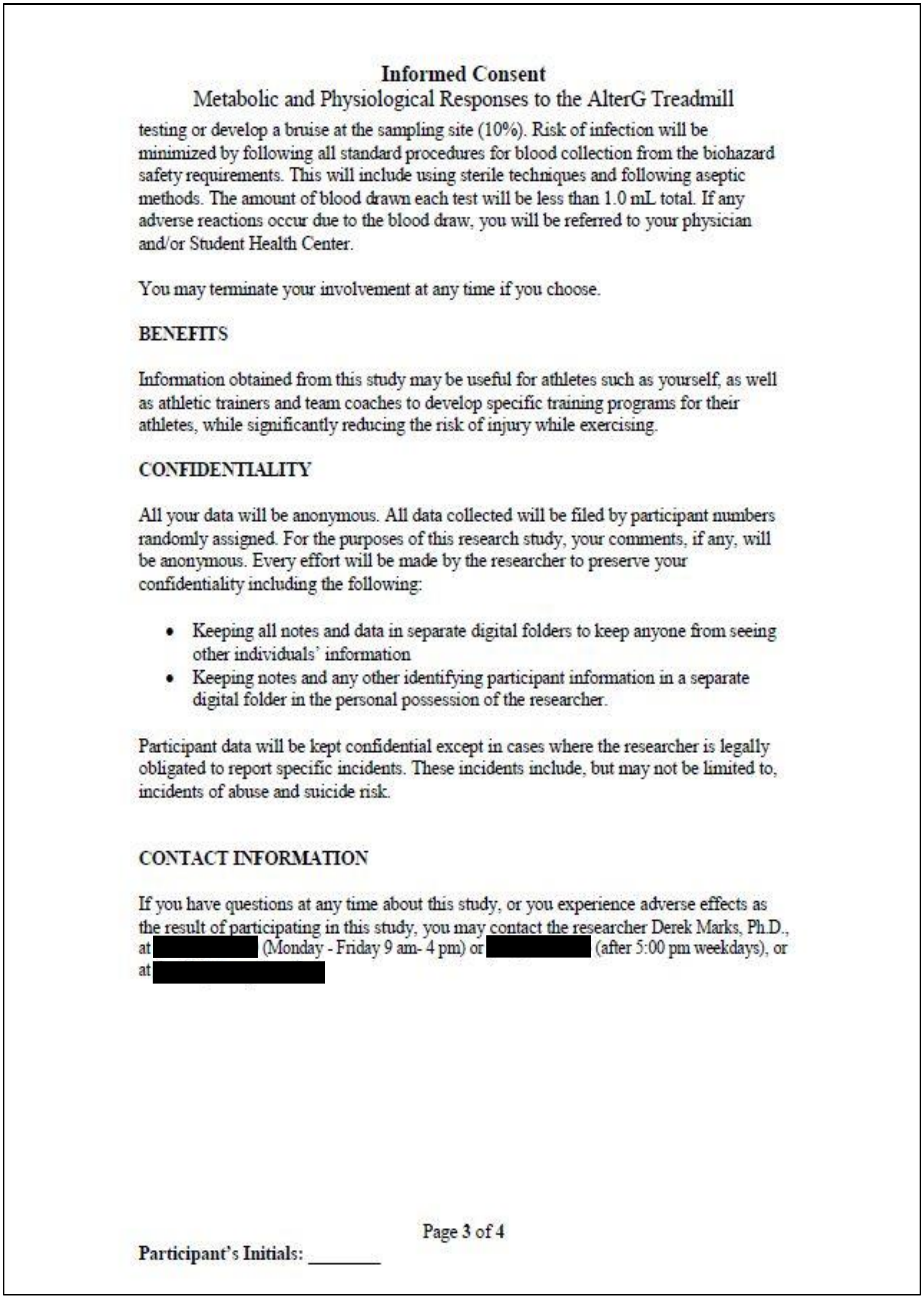
RISKS

Physical risk, such as lower body injury may occur if unfamiliar with equipment. We will dedicate as much time as needed prior to the first testing session for all participants to become familiarized (walk and run) on the AlterG before any official testing. This is to get the participant familiar with how the device operates and get a feel on how to comfortably run in the device.

During the exercise test and because running to exhaustion can lead to different risks, there are certain changes to be expected. They include increases in heart rate, blood pressure, breathing rate, local muscular fatigue, and sweating. There exists a possibility that certain abnormal changes may occur during this test and this includes abnormal blood pressure, fainting, and irregular heart rate and in rare instances heart attack, stroke, or death. Every effort will be made to minimize the risk be pre-evaluation of your health and fitness status. Emergency equipment and qualified personnel are available to deal with unusual situations that may occur.

Drawing mixed venous blood by a finger stick method approach can be associated with risks of pain, bruising, and infection. You also may get light headed after the exercise

Participant's Initials: _______



Informed Consent

Metabolic and Physiological Responses to the AlterG Treadmill

testing or develop a bruise at the sampling site (10%). Risk of infection will be minimized by following all standard procedures for blood collection from the biohazard safety requirements. This will include using sterile techniques and following aseptic methods. The amount of blood drawn each test will be less than 1.0 mL total. If any adverse reactions occur due to the blood draw, you will be referred to your physician and/or Student Health Center.

You may terminate your involvement at any time if you choose.

BENEFITS

Information obtained from this study may be useful for athletes such as yourself, as well as athletic trainers and team coaches to develop specific training programs for their athletes, while significantly reducing the risk of injury while exercising.

CONFIDENTIALITY

All your data will be anonymous. All data collected will be filed by participant numbers randomly assigned. For the purposes of this research study, your comments, if any, will be anonymous. Every effort will be made by the researcher to preserve your confidentiality including the following:

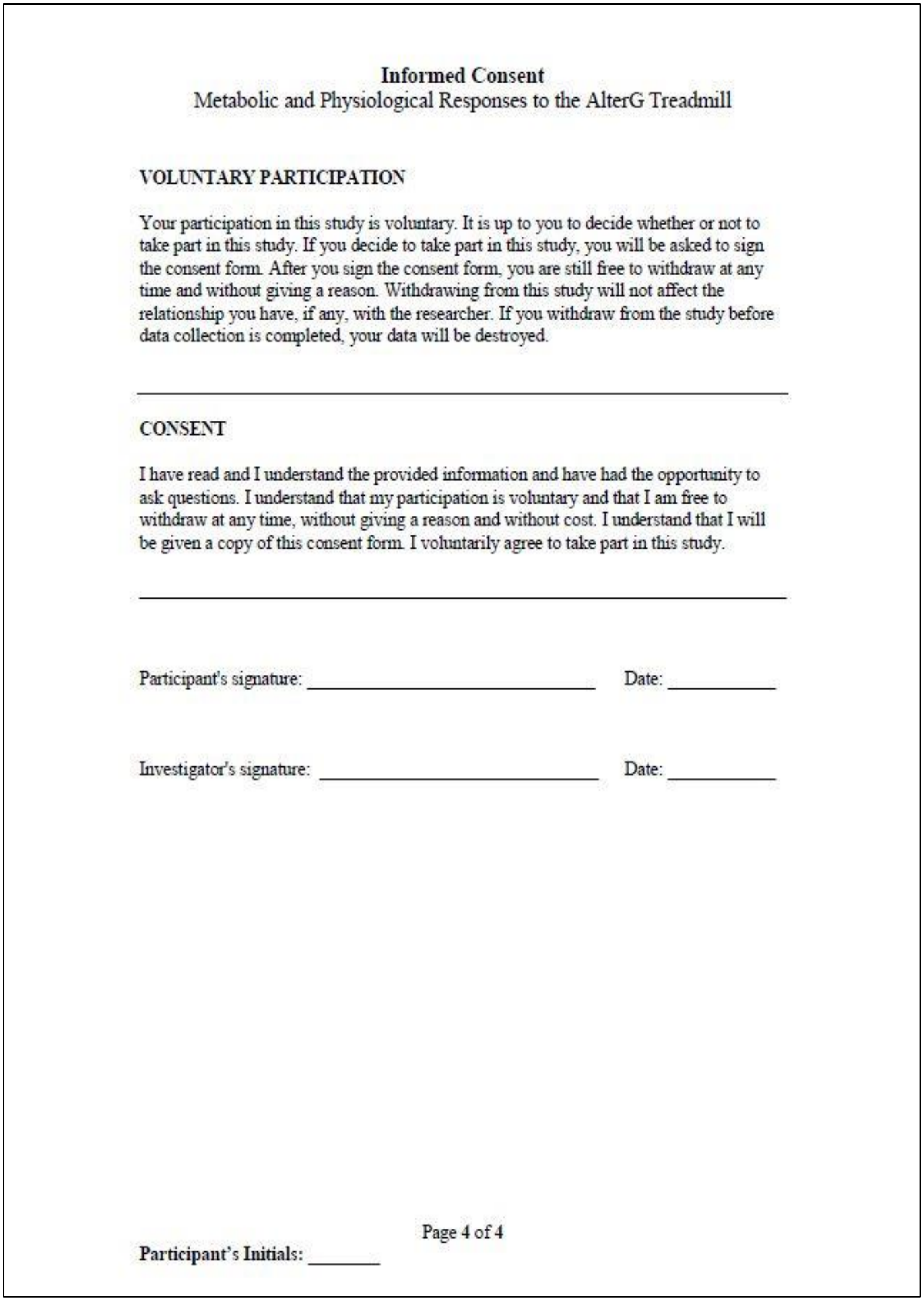
- Keeping all notes and data in separate digital folders to keep anyone from seeing other individuals' information
- Keeping notes and any other identifying participant information in a separate digital folder in the personal possession of the researcher.

Participant data will be kept confidential except in cases where the researcher is legally obligated to report specific incidents. These incidents include, but may not be limited to, incidents of abuse and suicide risk.

CONTACT INFORMATION

If you have questions at any time about this study, or you experience adverse effects as the result of participating in this study, you may contact the researcher Derek Marks, Ph.D., at [redacted] (Monday - Friday 9 am- 4 pm) or [redacted] (after 5:00 pm weekdays), or at [redacted]

Participant's Initials: _______



Informed Consent
Metabolic and Physiological Responses to the AlterG Treadmill

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide to take part in this study, you will be asked to sign the consent form. After you sign the consent form, you are still free to withdraw at any time and without giving a reason. Withdrawing from this study will not affect the relationship you have, if any, with the researcher. If you withdraw from the study before data collection is completed, your data will be destroyed.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study.

Participant's signature: ____________________________ Date: __________

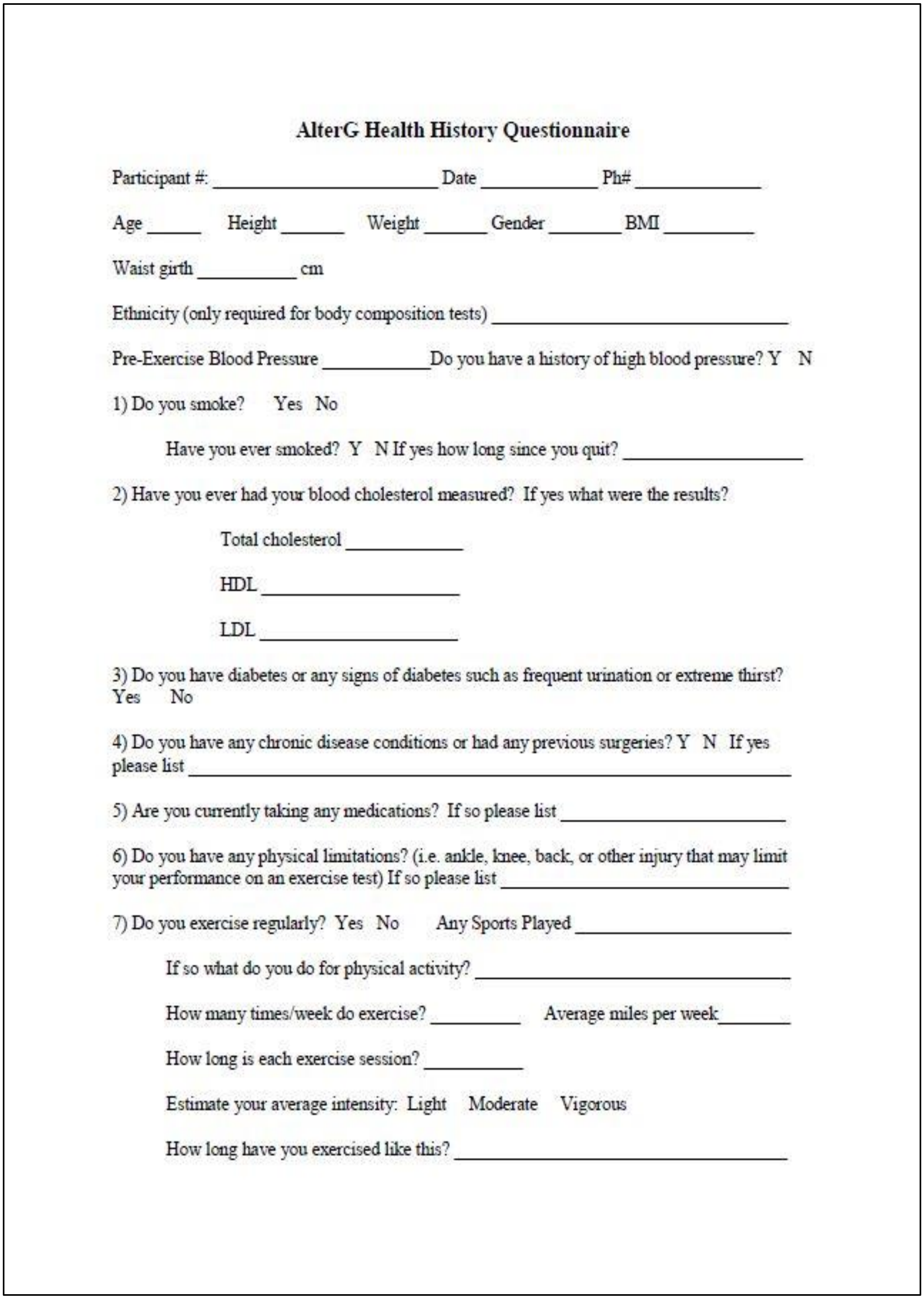
Investigator's signature: ____________________________ Date: __________

Page 4 of 4

Participant's Initials: _______

Appendix B

Health History Questionnaire



AlterG Health History Questionnaire

Participant #: ____________________ Date __________ Ph# __________

Age _____ Height ______ Weight ______ Gender _______ BMI ________

Waist girth _________ cm

Ethnicity (only required for body composition tests) ______________________

Pre-Exercise Blood Pressure __________ Do you have a history of high blood pressure? Y N

1) Do you smoke? Yes No

Have you ever smoked? Y N If yes how long since you quit? ______________

2) Have you ever had your blood cholesterol measured? If yes what were the results?

Total cholesterol __________

HDL ______________

LDL ______________

3) Do you have diabetes or any signs of diabetes such as frequent urination or extreme thirst? Yes No

4) Do you have any chronic disease conditions or had any previous surgeries? Y N If yes please list ____

5) Are you currently taking any medications? If so please list ________________

6) Do you have any physical limitations? (i.e. ankle, knee, back, or other injury that may limit your performance on an exercise test) If so please list ____________________

7) Do you exercise regularly? Yes No Any Sports Played ________________

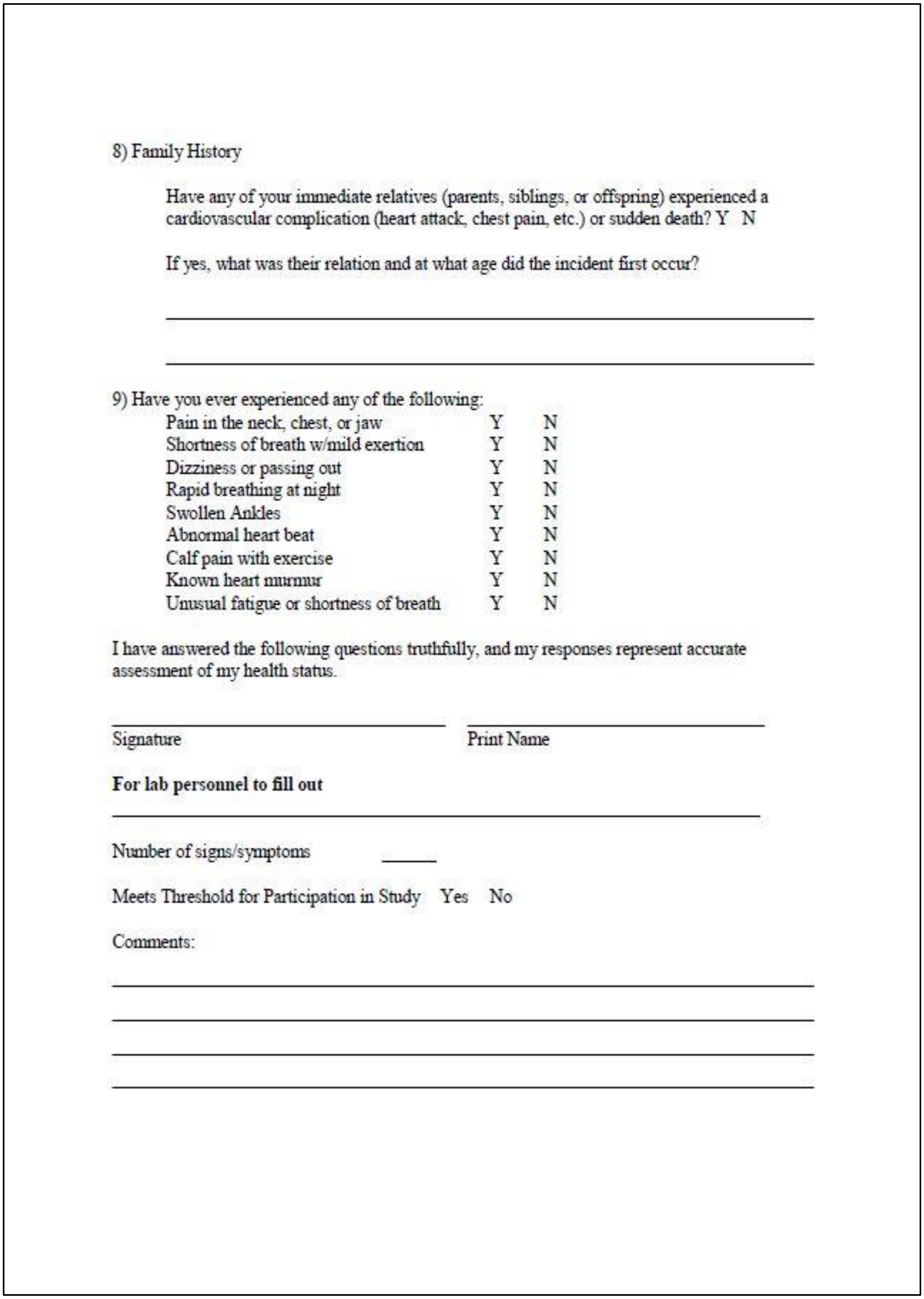
If so what do you do for physical activity? ______________________

How many times/week do exercise? ________ Average miles per week_______

How long is each exercise session? ________

Estimate your average intensity: Light Moderate Vigorous

How long have you exercised like this? ______________________



8) Family History

Have any of your immediate relatives (parents, siblings, or offspring) experienced a cardiovascular complication (heart attack, chest pain, etc.) or sudden death? Y N

If yes, what was their relation and at what age did the incident first occur?

____

____

9) Have you ever experienced any of the following:

Pain in the neck, chest, or jaw	Y	N
Shortness of breath w/mild exertion	Y	N
Dizziness or passing out	Y	N
Rapid breathing at night	Y	N
Swollen Ankles	Y	N
Abnormal heart beat	Y	N
Calf pain with exercise	Y	N
Known heart murmur	Y	N
Unusual fatigue or shortness of breath	Y	N

I have answered the following questions truthfully, and my responses represent accurate assessment of my health status.

__________________________ ________________________

Signature Print Name

For lab personnel to fill out

Number of signs/symptoms _____

Meets Threshold for Participation in Study Yes No

Comments:

____

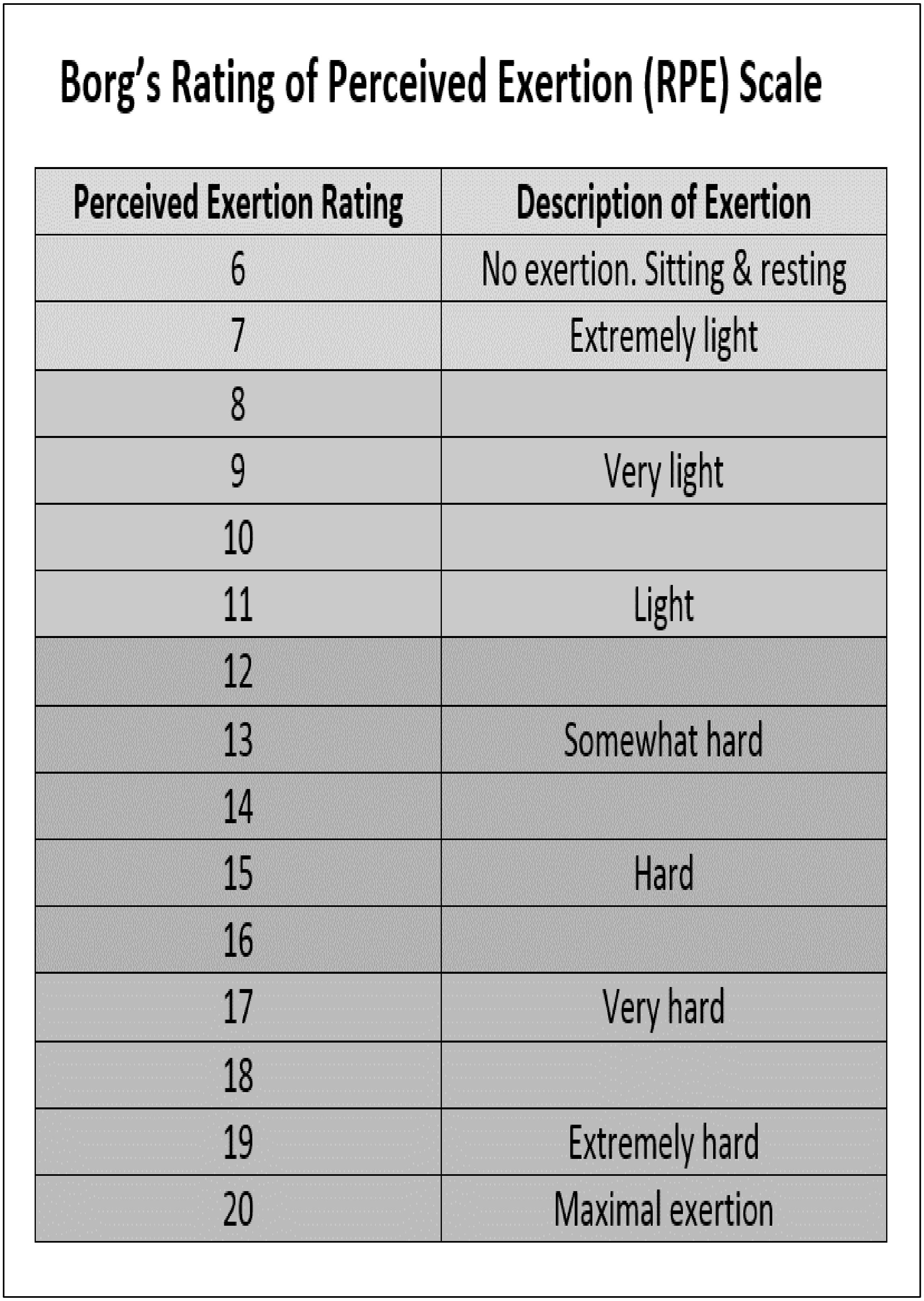
____

____

____

Appendix C

Borg RPE Scale



Borg's Rating of Perceived Exertion (RPE) Scale

Perceived Exertion Rating	Description of Exertion
6	No exertion. Sitting & resting
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion

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