INTERVAL TRAINING METHODS TO INCREASE PERFORMANCE MARKERS AND LOAD CARRIAGE IN TACTICAL PROFESSIONALS

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

DOCTOR OF PHILOSOPHY

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ABSTRACT

Load carriage is an inherent part of the military and other tactical occupations (e.g., law enforcement, firefighters). Variation in load carriage ranges from 7-60 kg and can increase energy expenditure as well as lead to higher injury risk. Various novel training methods such as low-intensity interval training (LIT) in combination with blood flow restriction (BFR) as well as high-intensity interval training (HIT) aim at enhancing critical velocity (CV), aerobic fitness, and load carriage performance. Two investigations identified the feasibility of LIT with BFR and the use of HIT to increase performance and load carriage. **Methods:** Twelve male participants (21.8 ± 1.5 yrs) underwent LIT with (BFR-LOAD) and without BFR (LOAD) loaded with 15% of their body mass to compare the acute metabolic and perceptual responses. Next, twenty adult participants (male = 15, female = 5) (age = 21.8 ± 1.5 yrs) completed 4-weeks of HIT (2 $d \cdot wk^{-1}$) to compare aerobic fitness and load carriage task performance. **Results:** Metabolic responses ($\dot{V}O_2$) were elevated 7% during BFR-LOAD (p = .001) compared with BFR familiarization and LOAD Condition. There were significant increases with CV (p = .005) and velocity at $\dot{V}$O2max ($v\dot{V}$O2max) (p = .037), but there was no statistical difference between the groups. There were load carriage performance improvements for the 3200 m task ($p < .001$) with a decrease of 9.8% in completion times. **Conclusion**: There was an increased metabolic response during the BFR-LOAD condition. Thus, there is a potential for BFR to limit the use of load carriage for individuals engaging in rehabilitation and reconditioning programs due to injury. Furthermore, four weeks of 2 $d \cdot wk^{-1}$ HIT was appropriate to see improvements in with aerobic measures of CV and $v\dot{V}O_2max$ as well as improvements in the load carriage task performances. LIT and HIT methods warrant continued research to increase aerobic fitness and load carriage performance.

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DEDICATION

This dissertation is dedicated to:

my parents as they always encouraged me;

my children who provided me with inspiration and determination;

my wife for her love and understanding;

the memory of my grandmother Phyllis, who always believed in me.

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LIST OF ABBREVIATIONS

1RM ....1-Repetition Maximum

3MT...3-Minute All-Out Test

ADEA ....Army Development & Employment Agency

ATP ....Adenosine Triphosphate

BMI ....Body Mass Index

BFR ....Blood Flow Restriction

CO_2 ....Carbon Dioxide

CP ....Critical Power

CRT ....Capillary Refill Time

CS..Critical Speed

CV ....Critical Velocity

D' ....Distance Prime

DeOxyHb ....Deoxygenated Hemoglobin

DVT ....Deep Venous Thrombosis

DXA ....Dual-Energy X-ray Absorption

FEV_1..Forced Expired Volume in 1 Second

FS ....Feeling Scale

FVC...Forced Vital Capacity

GET ....Gas Exchange Threshold

GRF...Ground Reaction Forces

GXT ....Graded Exercise Test

Hb ....Hemoglobin

HIT ....High-Intensity Interval Training

HR...Heart Rate

HRR ....Heart Rate Reserve

J...Joule

LBP ....Lower Back Pain

LC ....Load Carriage

LIT ....Low-Intensity Interval Training

LT..Lactate Threshold

MET ....Metabolic Equivalent

MVV ....Maximal Voluntary Ventilation

N·m ....Newton Meter

O_2 ....Oxygen

OEF..Operation Enduring Freedom

OIF ....Operation Iraqi Freedom

OxyHb ....Oxygenated Hemoglobin

PA-R ....Physical Activity-Rating

PCr ....Phosphocreatine

PGC-1α..Receptor Gamma Peroxisome proliferator

ROTC...Reserve Officer Training Corp

RPE ....Rate of Perceived Exertion

SKU..Standard Kaatsu Units

SmO_2...Muscle Oxygen Saturation

SV ....Stroke Volume

SWAT ....Special Weapons and Tactics

THb ....Total hemoglobin

VE ....Ventilation

US ....United States

$\dot{V}O_2$ ....Volume of Oxygen

$\dot{V}O_{2peak}$ ....Peak oxygen uptake

$\dot{V}O_{2max}$ ....Maximal Oxygen Uptake

WWII ....World War II

1. INTRODUCTION

1.1. Overview of the Problem

Tactical professionals, such as military, law enforcement, and fire and rescue personnel, require specialized equipment to complete their occupational demands and secure their physical safety (i.e., survivability). The additional equipment, also referred to as load carriage, can range from 7 to 60 kg dependent on the job and incident or mission-specific requirements (e.g., law enforcement patrol as compared to military combat patrol), and have the potential to cause subsequent occupational performance decrements (Dean, 2008; Dempsey, Handcock, & Rehrer, 2013; Knapik, Reynolds, Santee, & Friedl, 2012; Ricciardi, Deuster, & Talbot, 2008). With improvements in weaponry (both lethal and non-lethal), communications, and personal protective equipment though technological advances, load carriage continues to add to the physical demand of tactical professionals (Dempsey et al., 2013; Notley, Peoples, & Taylor, 2015; Ricciardi et al., 2008; Walker, Swain, Ringleb, & Colberg, 2015). Load carriage tends to limit the mobility and efficiency of tactical professionals through increased energy cost and perceptual effort to complete occupational tasks (Dempsey et al., 2013; Notley et al., 2015; Ricciardi et al., 2008; Walker et al., 2015). As a result, decrements related to job skill have been recorded and studied. In order to augment performance, specialized conditioning programs have been implemented to compensate for the load carriage concerns (Harman, Frykman, Palmer, Lammi, & Reynolds, 1997; Hendrickson et al., 2010; Pawlak, Clasey, Palmer, Symons, & Abel, 2015; Williams, Rayson, & Jones, 2002).

Specialized conditioning programs utilize collective modes of physical exercise to increase load carriage through aerobic exercise, resistance training, and exercise with progressive load carriage implemented within the programming. Studies that have combined resistance training with aerobic endurance training have observed significant increases in load carriage performance (Harman et al., 1997; Harman, Gutekunst, Fryman, Nindl, et al., 2008; Hendrickson et al., 2010; Knapik, 1997). Specificity is an essential concept to improving load carriage performance, where the training is relevant and appropriate for the desired effect (Hendrickson et al., 2010; Kraemer et al., 2001; Kraemer et al., 2004; Orr, Pope, Johnston, & Coyle, 2010). Interval training conducted under load would be more specific for conditioning and decrease the effects load carriage has on occupational performance (Hendrickson et al., 2010; Kraemer et al., 2001; Kraemer et al., 2004; Orr et al., 2010).

1.2. Statement of Purpose

The overarching purpose of this study was to evaluate the effects of interval training on enhancing load carriage performance through two different research protocols. The first investigation was an acute comparison of cardiovascular, metabolic, and perceptual responses with load carriage while walking with and without blood flow restriction (BFR). Currently, there is no literature on the use of BFR as a method to train or rehabilitate individuals for load carriage tasks. The second investigation evaluated the short-term adaptations from using the critical velocity (CV) model to prescribe two separate high-intensity interval training (HIT) regiments aimed at increasing load carriage performance. This research will add to the literature on the utility of the 3-minute all-out exercise test (3MT) and the use of CV for individualized training for tactical professionals. Moreover, this study investigated novel training methods for enhancing load carriage in tactical professionals.

1.3. Research Questions

1) *Investigation One:* Are there differences in cardiovascular, metabolic, and perceptual responses when walking with load carriage compared to walking with load carriage with BFR?
2) *Investigation Two*: How will two different HIT regiments with and without load carriage affect physiological adaptations and load carriage performance?

1.4. Dependent Variables

For investigation one, the dependent variables were the volume of oxygen ($\dot{V}O_2$), heart rate (HR), and local oxygen saturation (SmO_2) in the vastus lateralis. Also, physical activity rating was used to assess participants' fitness levels and perceptual responses as a result of exercise. For investigation two, the dependent variables were CV, *D'* (running capacities at speeds exceeding CV), and velocity at $\dot{V}O_{2max}$ as measures of the integrated bioenergetic system through the running 3MT. Body composition was measured in kg for body fat, lean mass, and total body mass. Peak torque (N·m) and total work (J) were used to measure knee extensor strength and endurance, respectively. Examination of time to completion (minutes: seconds) was used with the 400 m and the 3200 m load carriage tasks.

1.5. Independent Variables

For investigation one, the independent variables were BFR using Kaatsu training cuffs and the addition of a weighted vest equaling approximately 15% of the participants' body mass. For investigation two, the independent variables were the two separate interval prescriptions of HIT regiments with and without load carriage.

1.6. Limitations

For investigation one, recruitment of only healthy, male adults occurred due to the additional requirements for female participants (e.g., pregnancy testing and unable to be on birth control) with the addition of BFR. Safety contraindications for BFR training were also limitations excluding individuals with a history of deep vein thrombosis, cancer, open fracture, severe hypertension, stroke, diabetes, current inflection, acidosis, spinal cord injury, rhabdomyolysis; compromised circulation or peripheral vascular system (Biscontini, 2017; Heitkamp, 2015). With investigation two, there were limitations due to variables and the duration of the study. First, the participants in this study were recruited from North Dakota State University's Army Reserve Officer Training Corps (ROTC) department as they were more available for a training study over active law enforcement or firefighters; thus, the results may be less generalizable to other populations of tactical professionals (e.g., firefighters, law enforcement). Second, the concurrent training within the ROTC fitness program was not under the control of the researchers. Finally, there was no objective measurement of the physical activity completed outside of the training days, as this would have required additional resources over a significant period.

1.7. Delimitations

With the delimitations for both investigations, researchers made informed choices based on the existing literature. With investigation one, physical activity rating was used to assess fitness for demographics instead of completing a graded exercise test (GXT) to assess $\dot{V}O_{2max}$. For investigation two, instead of completing a GXT, the calculation of velocity at $\dot{V}O_{2max}$ from the 3MT was completed (Pettitt, Jamnick, & Clark, 2012). With limited logistical and time requirements, the 3MT is an ideal method for evaluating fitness and prescribing exercise for tactical professionals. Additionally, we recruited from the Army ROTC Program to keep a concurrent training program structure for the duration of the study for the participants. Load carriage performed through a commercially available weighted vest over issued equipment. The training program was only four weeks; other programs investigating load carriage improvement were eight to sixteen weeks. However, increases in CV has occurred in four-week training programs (Clark, West, Reynolds, Murray, & Pettitt, 2013).

1.8. Assumptions

There were a few assumptions made throughout the study. First, participants from ROTC engaged in the assigned physical training program (Monday and Friday) for the duration of the study. Secondly, the participants attended all eight training sessions (two times a week for four weeks). Finally, there were assumptions that participants honestly reported their demographic information (i.e., physical activity-rating).

1.9. Significance of Study

The information from this study will provide tactical strength and conditioning practitioners with an accurate method to prescribe load carriage exercise to increase fitness in the tactical professional population. The 3MT demonstrated utility in measuring both CV and *D'* with large groups of participants. Tactical professionals are often called upon to carry out continued operations requiring optimal aerobic conditioning. Additionally, they are often expected to face anaerobic challenges such as load carriage, sprinting, casualty evacuation, and subject apprehension. Thus, the results from the 3MT, with an integrated bioenergetic system approach, could be used to assess for technical readiness and used as standards for performance. High-intensity interval training (HIT) derived from 3MT to increase CV accurately is particularly relevant for improving tactical performance by decreasing the effects load carriage has on running economy and velocity.

1.10. Definitions

Blood Flow Restriction (BFR) is performed through the application of pressurized cuffs to the proximal portion of the extremity to maintain arterial inflow to the muscle while restriction venous return (Abe, Kearns, & Sato, 2006).

Critical velocity (CV) represents the speed maintained for an extended period by the aerobic energy systems (Poole, Burnley, Vanhatalo, Rossiter, & Jones, 2016).

Cardiac output is the product of heart rate (HR), and stroke volume (SV), which is the volume of blood pumped from the ventricle per beat

D' (n.b. pronounced D prime) is the running capacities at speeds exceeding CV (Jones, Vanhatalo, Burnley, Morton, & Poole, 2010b).

End-diastolic volume is the volume of blood in the ventricles at end load or filling (Higginbotham et al., 1986).

End-systolic volume is the volume of blood in the ventricle at the end of the contraction (Higginbotham et al., 1986)

Fighting load consists of the soldier's uniform, load bearing equipment, weapon, ammunition, and rations.

Forced vital capacity (FVC) is defined as the amount of air a person can exhale on forced breath (Muza, Latzka, Epstein, & Pandolf, 1989; Phillips, Ehnes, Stickland, & Petersen, 2016; Walker et al., 2015)

High-intensity interval training (HIT) is relatively high-intensity exercise bouts alternated with relatively low-intensity recovery periods (Berger, Tolfrey, Williams, & Jones, 2006).

Load carriage is the external load professionals carry as part of their occupational demands such as duty belts, equipment, weapons, body armor, and different types of protective gear (Knapik et al., 2012).

Structural firefighting defined as "the activities of rescue, fire suppression, and property conservation in building or other structures" (Association, 2012).

Velocity at $\dot{V}O_{2max}$ is the 90 s speed value in the running 3-minute all-out test as a predictor of velocity at $\dot{V}O_{2max}$ (Pettitt et al., 2012).

Wildland firefighting covers “the activities of fire suppression and property conservation in woodlands, forests, grasslands, brush, prairies, and other such vegetation not within buildings or structures” (Association, 2005).

2. LITERATURE REVIEW

2.1. Introduction

Tactical professionals, such as military, law enforcement, and fire and rescue personnel, require specialized equipment to complete their occupational demands and secure their physical safety (i.e., survivability). The additional equipment, also referred to as load carriage, can range from 7 to 60 kg dependent on the job and incident or mission-specific requirements (e.g., law enforcement patrol as compared to military combat patrol), and have the potential to cause subsequent occupational performance decrements (Dean, 2008; Dempsey et al., 2013; Knapik et al., 2012; Ricciardi et al., 2008). With improvements in weaponry (both lethal and non-lethal), communications, and personal protective equipment though technological advances, load carriage continues to add to the physical demand of tactical professionals (Dempsey et al., 2013; Notley et al., 2015; Ricciardi et al., 2008; Walker et al., 2015). Although this tactical professional population is composed of about 3.5 million professionals in the United States (US), limited comprehensive statistics are available outside of the military population (Nindl et al., 2013).

With the recommendation from the US Army Development and Employment Agency (ADEA), specialized programs were implemented to condition soldiers to carry increased load carriage (Knapik et al., 2012). These specialized programs utilize collective modes of physical exercise to increase load carriage through aerobic exercise, resistance training, and progressive load carriage within exercise programming. Studies that have combined resistance training with aerobic endurance training have observed substantial increases in load carriage performance (Harman et al., 1997; Harman et al., 2008; Hendrickson et al., 2010; Knapik, 1997). Specificity is the essential concept to improving load carriage performance, where the training is relevant and appropriate for the desired effect (Hendrickson et al., 2010; Kraemer et al., 2001; Kraemer et al., 2004; Orr et al., 2010).

Injuries sustained from load carriage that are generally minor and acute can affect mobility and ability to complete occupational tasks (Knapik et al., 2012). The majority of the anatomical locations where these injuries occur include the back, knees, feet, and shoulders (Knapik, 2014; Knapik, Reynolds, & Harman, 2004; Orr, Johnston, Coyle, & Pope, 2015). To assist in the prevention of these types of injuries, relevant research suggests more specific, personalized, and tailored physical training programs (Orr et al., 2010). Understanding and preventing potential injuries, as well as safely utilizing load carriage, are critical when conducting these conditioning programs.

Overall, the purpose of this review is to provide a comprehensive examination of load carriage including a historical perspective and the various acute physiological and biomechanical changes that alter performance. Secondly, the review will focus on exercise countermeasure training programs that have been developed to mitigate the adverse effects of load carriage. This section will discuss numerous aerobic and anaerobic performance markers as well as methods to optimize exercise prescription in both traditional and experimental training programs. Finally, there will be an in-depth analysis of the injuries associated with load carriage as well as an examination of other safety considerations associated with exercise programming.

2.2. Load Carriage

2.2.1. Introduction

Load carriage is defined as an external load carried by professionals as part of the demands of their occupation, which takes the form of duty gear, equipment, weapons, body armor, and different types of protective gear (Dennison, Mullineaux, Yates, & Abel, 2012;

Knapik et al., 2004; Loverro, Brown, Coyne, & Schiffman, 2015; Ricciardi et al., 2008). Tactical professionals (e.g., military, law enforcement, fire, and rescue) often face load carriage as a fundamental problem in their environments. Due to the mission-essential nature of most of these occupations, the load tends to be more, “absolute” as the loads have a little variation from height and weight of the professional (i.e., body armor, weapons). In contrast to absolute loading, “relative” loading is a fraction of one’s body mass (i.e., 20%) (Phillips, Stickland, Lesser, & Petersen, 2016; Solomonson, Dicks, Kerr, & Pettitt, 2016). Load carriage tends to limit the mobility and efficiency of tactical professionals through increased energy cost and perceptual effort to complete occupational tasks/demands (Dempsey et al., 2013; Notley et al., 2015; Ricciardi et al., 2008; Walker et al., 2015). As a result, decrements related to job skill have been recorded and studied. In order to augment performance, specialized conditioning programs have been implemented to compensate for the load carriage concerns (Harman et al., 1997; Hendrickson et al., 2010; Pawlak et al., 2015; Williams et al., 2002).

Within the tactical professional population, variations in load carriage can range from 7 to 60 kg and will be dependent on specific occupations and operations conducted (Dean, 2008; Dempsey et al., 2013; Ricciardi et al., 2008). With a considerable amount of variation in load carriage weights, one singular method of training cannot meet the demands of all tactical professionals. For example, military operations in remote combat locations often burden service members with loads greater than 60 kg (Dean & DuPont, 2003; Knapik et al., 2004; Orr, Pope, Johnston, & Coyle, 2012). The weight of the load can be dependent on the range and length of the operation with an average load of 30 kg in the modern combat battlefield (Dean & DuPont, 2003). Similarly, law enforcement and firefighters work with fatiguing ranges of load carriage from 7 to 25 kg while performing various physically demanding occupational tasks (Dennison et al., 2012; Ricciardi et al., 2008). Load carriage also limits tactical professionals' mobility and speed during these tasks (Dempsey et al., 2013; Dennison et al., 2012; Lewinski, Dysterheft, Dicks, & Pettitt, 2015). Due to vast ranges of load carriage weights and the adverse effects on performance within the tactical population, this topic has been of great interest to military, law enforcement and firefighting agencies.

2.2.2. Historical Perspective

Load carriage has been observed in military units for centuries dating back to the Greek Hoplites and Roman Legionnaires (Knapik et al., 2012). However, there is little information on the efforts to study load carriage in the US before World War II (WWII) (Knapik et al., 2012). During that time, a soldier's load carriage was developed by the Quartermaster General, which was an attempt to unburden the solider by providing him with only the items needed for combat. Throughout history, many armies utilized packs, carts, and pack animals to lessen the load carried by soldiers. Even more recently, the use of motorized vehicles (i.e., all-terrain vehicles) has decreased equipment carried by the soldier in rugged areas of Iraq and Afghanistan (Kennedy, 2003). External loads carried by US soldiers have seen a nearly linear increase from 16 kg during WWII to 29 kg during Operation Enduring Freedom/Operation Iraqi Freedom (Figure 1) (Knapik et al., 2004; Nindl et al., 2013). Even as technology advances, there is an increasing trend of the weight required to be carried by these tactical professionals.

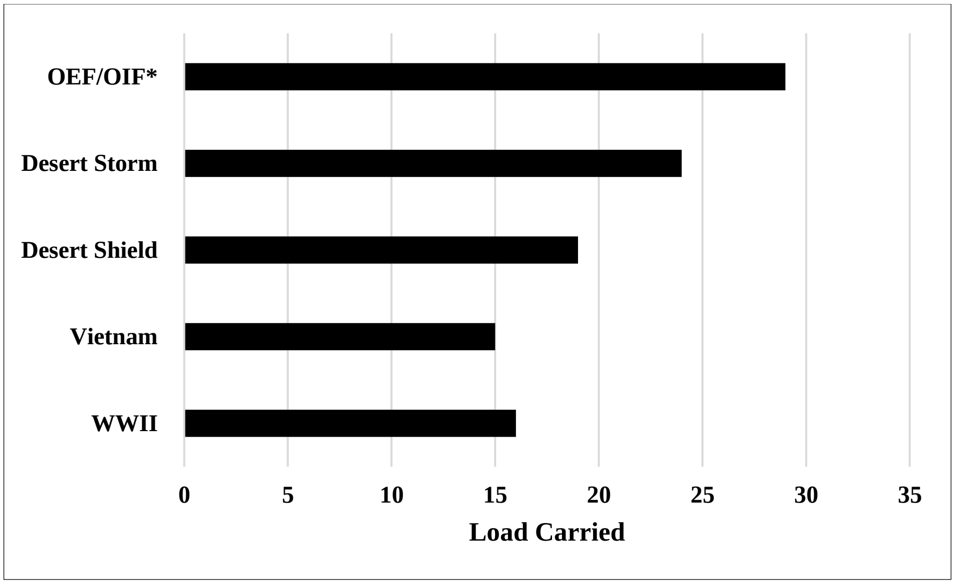

Figure 1. Loads Carried by US Soldiers through History
Soldier Loads Carried by US Soldiers through History from WWII to OEF and OIF (Knapik et al., 2004), *Operation Enduring Freedom (OEF)/Operation Iraqi Freedom (OIF)

Early studies completed by the US military focused on the effects of load carriage and the negative relationship with combat effectiveness on the soldiers (Bailey & McDermott, 1952). Through the use of metabolic and energy expenditure data, recommendations were made that riflemen carry 18 kg in the worst conditions and 25 kg for a maximum march load (Bailey & McDermott, 1952). The notion of "load echeloning" is defined as the different loading of soldiers with fighting load and existence load or approach march load. Load echeloning further developed in 1987 by the ADEA providing definitions for doctrinal development in load carriage (Agency, 1987). “Combat load” was defined as the mission-essential equipment required for the soldiers to fight and complete their mission (Agency, 1987). A combat load was divided into fighting load and approach march load. Carrying a fighting load when contact with the enemy was expected (Agency, 1987). Fighting load consists of the soldier's uniform, load bearing equipment, weapon, ammunition, and rations. The approach march load also included a pack, sleeping bag, extra uniforms, extra ammunition, and extra rations. The march load quantities were dependent on the type of mission and duration. Today those recommended loads by US Army doctrine (Army Techniques Publication 3-21.18, Foot Marches) for fighting and approach march are 22 kg (or 30% body weight) and 33 kg (or 45% body weight), respectively (Army, 2017). This information provides commanders of military units with objective measures for mission planning and physical training. With the ADEA proposed five approaches to deal with the loads carried by soldiers (Agency, 1987), the development of special physical training programs to condition soldiers served as the more beneficial method.

On the modern battlefields, service members are required to carry substantial loads during combat operations (Dean, 2008). The study by Dean (2008) measured the loads carried by soldiers while engaged in low-intensity conflict provided data on actual loads carried by various duty positions (i.e., rifleman, grenadier, fire team leader, etc.) (Dean, 2008). The research concluded the average fighting load carried by light infantry soldiers is 29 kg with an approach march load of 46 kg (Dean, 2008). Dean (2008) noted that recent improvements in ballistic protection (e.g., interceptor body armor, advanced combat helmet) had increased soldier survivability, but had decreased mobility and endurance. Body armor and the protective helmet accounted for roughly 31% of the fighting load of the infantry soldiers (Dean, 2008). With the technological advances through history, the result has been the need for additional weapons for firepower, increases in personal protection and communication abilities; increasing the load placed on the tactical professionals (Nindl et al., 2013).

2.2.3. Occupational Loads

2.2.3.1. Military Personnel

The requirements for load carriage in the military are dependent on occupation and specific job requirements. The composition can include protective gear (e.g., body armor, helmet) that will protect them from small arms fire and fragments from explosions. Additional silicon carbide/boron carbide plates can be added to the body armor for increased survivability against larger caliber rifles and machine gun fire (Knapik et al., 2012). The weight of this body armor is approximately 13 kg (Konitzer, Fargo, Brininger, & Reed, 2008). Additionally, specific combat equipment can include different weapon systems, ammunition, communication devices, batteries as well as sustainment supplies (e.g., food and water); thus, increasing the load (Johnson, Knapik, & Merullo, 1995).

Occupational requirements in the military determine the frequency and the duration the load-bearing equipment is worn. Combat arms service members (i.e., Infantry, Special Operations) can expect to wear load-bearing equipment more often than those in combat support positions (Hollander & Bell, 2010). During combat operations, all service members must be able to conduct their warfighter tasks wearing their assigned equipment. This composition of assigned equipment is defined as the fighting load as discussed previously. Additionally, soldiers could be wearing their load bearing equipment for more than four hours per day. Regardless of the assigned occupation, it is essential for the service member to perform these tasks with fighting load (22 kg or 30% body weight).

2.2.3.2. Public Safety

Extensive research has been conducted to understand the effects of load carriage in the military; however, less research investigates the effects load carriage has in firefighting and police populations. Firefighting is subdivided into two main groups: 1) Structural firefighting defined as "the activities of rescue, fire suppression, and property conservation in building or other structures" (Association, 2012); 2) Wildland firefighting covers “the activities of fire suppression and property conservation in woodlands, forests, grasslands, brush, prairies, and other such vegetation not within buildings or structures" (Association, 2005). Firefighters are often required to wear personal protective equipment while performing a variety of physical, occupational tasks (i.e., carrying equipment, hose handling, stair climbing) (Eglin & Tipton, 2005). Structural firefighting can include personal protective clothing (e.g., turnout gear), self-contained breathing apparatus, and specialized equipment (e.g., entry tools, fire suppression tools) (von Heimburg, Rasmussen, & Medbo, 2006). The additional equipment can burden firefighters with working loads ranging from 15 to 30 kg. Wildland firefighters carry equipment (e.g., axes, chainsaws) as well as sustainment supplies (e.g., food, water) that can total in excess of 20 kg (Rodriguez-Marroyo et al., 2012). Typically, structural firefighters are not required to wear gear during duty days except when responding to a fire call, whereas wildland firefighters often carry the equipment throughout an entire shift while walking through rough terrain.

Similar to the military, law enforcement personnel are beginning to carry more weight due to technological advances in body armor and the increases in non-lethal capabilities (e.g., tasers) (Lewinski et al., 2015; Ramstrand, Zugner, Larsen, & Tranberg, 2016). Law enforcement can have separate populations consisting of patrol, administrative, traffic, highway regulation, and specialty units that would determine what protective equipment/duty gear they are required to wear. Officers carrying duty belts along with protectives vests can carry an external load of approximately 7.5 to 9 kg (Dempsey et al., 2013). This external load is worn during the workday (e.g., 10-12 hours) where officer tasks or duties could vary from low intensity to short bouts of high-intensity activity (Dawes et al., 2017; Lewinski et al., 2015).

2.2.4. Physiological Effects

The ability to perform aerobic work is significantly decreased with the addition of load carriage (Knapik et al., 2004; Ricciardi et al., 2008). These decreases are due to the regular increases in the energy cost of the increasing load carriage (Beekley, Alt, Buckley, Duffey, & Crowder, 2007). With the increasing demand from load carriage, the physiological impacts include increased rate of perceived exertion (RPE), elevated oxygen consumption ($\dot{V}O_2$), enhanced vertical ground reaction forces (GRF), decreased work capacity, and decreased tolerance to continue aerobic work (Notley et al., 2015; Phillips, Stickland, et al., 2016; Puthoff, Darter, Nielsen, & Yack, 2006; Ricciardi et al., 2008; Taylor, Peoples, & Petersen, 2016). To summarize, there is a reduction in the work completed from the additional weight of load carriage. Loss of performance can be dependent on factors such as the body size, fat free mass, muscular strength, physical fitness level and the intensity of the task of the tactical professional (Knapik, Harman, Steelman, & Graham, 2012; Notley et al., 2015; Phillips, Stickland, et al., 2016).

2.2.4.1. Cardiovascular Response

Cardiovascular responses to load carriage are similar to those experienced during aerobic exercise. Tactical professionals will experience an increase in cardiac output (the amount of blood pumped by the heart) via sympathetic nerve stimulation that increases both HR and stroke volume (SV). With the increase in cardiac output, the vascular system can redistribute blood to skeletal muscle with an increased demand for oxygen (O_2) and energy. As the heart increases in contractility, blood pressure (mostly systolic) will also see an acute increase. The rate of the response has shown to be dependent on factors related to load carriage (i.e., load weight, the speed of movement, terrain) (Knapik, Harman, & Reynolds, 1996; Pandolf, Givoni, & Goldman, 1977). Followfield et al. (2012) investigated the cardiovascular responses of 12 male recruits during a 19.3 km load carriage march with 31 kg (Fallowfield, Blacker, Willems, Davey, & Layden, 2012). The recruits marched at mean speed of 4.3 $km \cdot h^{-1}$ that resulted in a mean HR of

147 ± 10 beat per min representing 64 ± 5 % of heart rate reserve (HRR) considered in the hard-physical activity zone. Negative correlations were found between body mass and absolute $\dot{V}O_{2max}$ with %HRR during load carriage. The findings suggest that lighter individuals are at a disadvantage during load carriage tasks with an absolute load due to the increase in cardiovascular strain or %HRR and oxygen costs that are experienced (Fallowfield et al., 2012). Another study investigating 30 minutes of marching at 6 $km \cdot h^{-1}$ using three different loads (30, 50 and 70% of body mass) with 10 male Army officers (Beekley et al., 2007). With the increase in the load there was a systematic increase with $\dot{V}O_2$ (17%), ventilation (VE) (24%) and HR (12%) (Beekley et al., 2007). Beekley et al. (2007) suggest that HR and relative energy coast are fairly linear for fit male subjects during road marches. Concluding that cardiovascular strain increases with the amount of relative load carried.

Physically fit individuals, based on aerobic capacity, tend to have lower heart rates during exercise showing increased stroke volume and myocardial contractility (Jones & Carter, 2000). Physiological adaptations are mostly due to the increase in exercise economy or the O_2 uptake required at a given absolute exercise intensity as the body becomes more efficient at exercise (Jones & Carter, 2000). During exercise, increased venous return to the heart will often cause a slight increase in end-diastolic volume (i.e., the volume of blood in the ventricles at end load or filling) (Higginbotham et al., 1986). Diastole will be longer as the HR is slower, allowing the heart more time to fill between contractions. The sympathetic activation of the heart during exercise increases the ventricular contractility that subsequently decreases the end systolic volume (the volume of blood in the ventricle at the end of the contraction) (Higginbotham et al., 1986). It is well established with the physiological adaptations to exercise improving physiological capacities will increase exercise economy. Thus, although adding a load carriage will decrease cardiovascular function, using load carriage as a training mechanism can improve the capacity of the cardiovascular system.

2.2.4.2. Metabolic Demand

The metabolic cost associated with walking can explain the increase in energy needed to generate muscular force during the stance phase for individuals under load (Griffin, Roberts, & Kram, 2003). The metabolic cost of walking was observed at different speeds (0.5, 1.0, 1.5, and 2.0 $m \cdot s^{-1}$) in four men and four women while carrying loads equal (0, 10, 20 and 30%) of their body mass. The researchers found the metabolic cost was directly proportional to the cost of generating muscle force or the rate of activation with speed and load (Griffin et al., 2003). When increasing load carriage of an individual, the kinetic energy required will also increase, which results in the loss of efficiency and an increase in O_2 demand (Clark, West, et al., 2013; Solomonson et al., 2016). The result of load carriage has shown a systematic increase in $\dot{V}O_2$, HR and VE (Abe, Muraki, & Yasukouchi, 2008; Beekley et al., 2007; Phillips, Stickland, et al., 2016; Walker et al., 2015). This metabolic cost has been shown to increase exponentially as velocity increases (Puthoff et al., 2006). When load carriage is not standardized for body mass, further increases in metabolic demand can be seen in smaller individuals (Beekley et al., 2007). Indeed, the changes in velocity under load can reduce mechanical efficiency due to the proportionately faster rise in $\dot{V}O_2$ toward $\dot{V}O_{2max}$ evoked by the recruitment of type II muscle fibers (Burnley & Jones, 2007).

The energy cost of load carriage seems to indicate a linear relationship with absolute loads and relative loads (% of body mass) of up to 65 kg and 70% of body mass at walking speeds (< 6.5 $km \cdot h^{-1}$) (Beekley et al., 2007; Quesada, Mengelkoch, Hale, & Simon, 2000). In a recent study, researchers investigated the physiological responses and performance in males with and without load carriage (25 kg backpack) during a GXT on a treadmill (Phillips, Stickland, et al., 2016). Peak oxygen uptake ($\dot{V}O_{2peak}$) was reduced (11.1%) and a reduction in exercise performance time (29.8%) was recorded from the additional load (Phillips, Stickland, et al., 2016). Additionally, the investigators found, exercising at ventilatory threshold resulted in a decrease in $\dot{V}O_2$ (3.9%) with a reduction in power output during treadmill exercise (23.9%) (Phillips, Stickland, et al., 2016). The researchers reported the difference in the test duration had a significant correlation ($R = -0.47$) with the body mass of the participant, suggesting that heavier individuals may be more tolerant of the work involved with the addition of the load carriage (Phillips, Stickland, et al., 2016).

Similar to the methodology previously reported by Phillips, Stickland, et al. (2016), the researchers investigated $\dot{V}O_{2peak}$, expired flow volume, RPE, and blood lactate in individuals with and without a load carriage weighing 45 kg (Phillips, Ehnes, et al., 2016). Phillips, Ehnes, et al. (2016) observed a 10% decrease in $\dot{V}O_{2peak}$ as well as a 5.8% decrease in forced expired flow volume with the addition of a 45 kg backpack. However, the researchers did not report a difference in the RPE or blood lactate during maximal exercise with load carriage. Phillips, Ehnes, et al. (2016) concluded that assessments for physiological readiness for work in occupations where heavy load carriage should be required to improve safety and effectiveness.

During an investigation, researchers observed the metabolic cost with the addition of body armor (10 kg) with 34 military personnel during two different walking speeds (Ricciardi et al., 2008). From a rested condition, participants walked with the body armor at 4.5 metabolic equivalents (METs) that increased energy expenditure to 42 $kcal \cdot h^{-1}$. When participants intensified to a moderate pace or 9 MET (similar to military maneuvers), energy expenditure increased to 126 $kcal \cdot h^{-1}$ (Ricciardi et al., 2008). Significant increases ($p < 0.001$) in the metabolic cost of walking at slow and moderate paces were observed (Ricciardi et al., 2008). Additionally, at the moderate pace (9 MET), blood lactate levels were 68% higher when wearing the body armor (Ricciardi et al., 2008). The results from this study show the potential for marked decreases in performance when individuals are wearing body armor while completing military maneuvers.

Terrain, varying from pavement, dirt, gravel, swamp, sand, and snow and surface can be contributing factors to energy cost during load carriage (Knapik et al., 2004). Energy cost can increase from 8 to 60% over these various terrains and can decrease time to fatigue for tactical athletes during movement (Haisman & Goldman, 1974). Following previous work (Givoni & Goldman, 1971), researchers developed an equation, which predicted the energy cost of load carriage (Pandolf et al., 1977). The Pandolf equation considered: body mass, load weight, terrain, velocity, and grade, as a way to predicted energy cost for an individual. The equation had a few limitations such as downhill walking and the demand for increased energy over time. The equation also did not account for the distribution of the load on the body (e.g., backpack vs. pack with hip belt). The effects of load carriage are multifactorial, indicating the need for more collaborative efforts to evaluate and create prediction models to better understand the cost of load carriage for tactical professionals.

2.2.4.3. Pulmonary Function

Tactical professionals often have loads positioned on their upper torsos that can affect pulmonary function, especially during heavy exercise. Thoracic load carriage alters pulmonary function and ventilatory mechanics during treadmill exercise in males with and without load carriage (25 kg backpack) during a GXT on a treadmill (Phillips, Stickland, et al., 2016). During 12.25 km treadmill marches with different load configuration (21, 26, 33, and 43 kg) was found to be the source for increased restrictive ventilatory impairment through reducing lung volumes at rest (Armstrong, Risius, Wardle, Greeves, & House, 2017). Furthermore, research suggests that with increasing load, tactical professionals will see a decrease in forced vital capacity (FVC), which is defined as the amount of air a person can exhale on forced breath (Muza et al., 1989; Phillips, Ehnes, et al., 2016; Walker et al., 2015). Common loads that were used to test pulmonary function ranged from unloaded or 0 kg up to 45 kg. To form the load carriage, the researchers used an Army All-purpose lightweight individual carrying equipment backpack (Muza et al., 1989), a weighted vest (similar to body armor) (Walker et al., 2015) or an 80-L backpack (Phillips, Ehnes, et al., 2016). The researchers measured the subjects' pulmonary function (forced expired volume in 1 second (FEV_1), FVC, and maximal voluntary ventilation (MVV) with each load. Muza et al. (1989) completed a smaller study utilizing only five young male subjects. Researchers found statistical decreases in FVC and FEV_1 ($p < 0.01$) with the addition of load from 0, 10 to 30 kg. However, they did not see any further decrements of MVV with additional load from 10 to 30 kg (Muza et al., 1989).

Walker et al. (2015) investigated 42 subjects (male = 22, female = 20) during maximal incremental treadmill tests while wearing four different loads (0, 10, 20, and 30 kg). One of the main findings was that with increasing loads worn on the upper torso resulted in decreased pulmonary function (e.g., FVC, FEV_1, and MVV) resulting in parallel decreases in aerobic performance and capacity (Walker et al., 2015). With thoracic loading of 30 kg, FVC was reduced by 9.0%, and FEV_1 was reduced by 9.7%. Phillips, Stickland, et al., (2016) recruited 19 healthy active males using a repeated measures design with GXTs in an unloaded and 45-kg condition along with submaximal exercise bouts with weights of 15, 30 and 45 kg. With thoracic loading of 45 kg, FVC and FEV_1 were reduced by 5.0 and 5.8%, respectively. Additionally, the

45 kg thoracic load carriage increased the exercise ventilatory requirement for oxygen (Phillips, Ehnes, et al., 2016). In summary, heavy thoracic load carriage can alter pulmonary function and ventilatory mechanics.

2.2.5. Biomechanical

The success of the tactical professional is often dependent on the mobility of the personnel. External load carriage can compromise the mobility of these professionals that could differ in characteristics (e.g., size, shape, weight) (Harman et al., 2001; Knapik et al., 2004). Load carriage systems can vary from the type of frame (e.g., internal or external) to the addition of hip belts that can influence: force on shoulders via straps, the center of mass of the load, and comfort (Knapik et al., 2004). Different types of backpacks have been shown to affect the biomechanics of gait due to the difference in load locations (Harman et al., 2001). An increase in load carriage is inversely related to stability due to changes in gait and altered GRF. The combination of decreased stability and altered gait as well as GRF potentially increase the risk for injury (Birrell & Haslam, 2010; Birrell, Hooper, & Haslam, 2007; Harman et al., 2001; Knapik et al., 2004; Lewinski et al., 2015; Quesada et al., 2000). Gait is the kinematics of walking concerning; stride frequency, range of motion, time spent in the swing and stance phase, the center of gravity, stride time, stride length, and GRF (Birrell & Haslam, 2010; Harman et al., 2001). Birrell et al. (2007) studied GRF with progressive load carriage conditions starting from 0 kg (with just military boots) with trials of 8, 16, 24, 32, and 40 kg. The authors found vertical and anteroposterior GRF parameters increased proportionally (5-6%) with each load condition cumulatively increasing ground reaction forces (Birrell et al., 2007). Furthermore, females generally walk with shorter stride lengths and increased stride frequency which increases their contact with the ground further increasing GRF when generally compared to males (Birrell et al., 2007; Knapik et al., 2004). This increase of GRF could bring about lower extremity injuries to the bone, cartilage, soft tissue.

In a study incorporating young, healthy law enforcement students, participants wore a 9 kg weight belt to simulate the average load of duty gear (i.e., body armor and duty belt), equating to 11.47 ± 1.64% of their body mass (Lewinski et al., 2015). The participants completed sprint trials from four various starting positions (e.g., forwards, backward, 90 degrees turn to the left, and a 90 degree turn to the right) in a randomized order with and without the weight belt. Lewinski et al. (2015) observed significant decreases in stride velocity (5%) and acceleration (13%). In contrast, they observed no change in stride length demonstrating increases in ground contact time. The authors concluded the added time on the ground attributes to the increased eccentric loading of the muscles needing more time to reverse the downward motion and propel the body forward by pushing off the ground (Lewinski et al., 2015). These data suggest the need to prepare tactical professionals, through training and fitness, to better prepare for the occupational demand they will face while wearing duty, protective gear, and equipment.

2.2.6. Impact on Occupational Tasks and Performance

Tactical professionals are encumbered with load carriage, providing essential equipment to complete their jobs results in decreases in performance of functional tasks. Load carriage can also lead to adverse effects on critical military tasks such as fitness tests, marksmanship, and grenade throwing (Swain, Ringleb, Naik, & Butowicz, 2011). The cost of load carriage is also a factor on performance variables in other professions with effects on finding cover, catching a fleeing subject or fighting a fire (Dempsey et al., 2013; Dennison et al., 2012; Lewinski et al., 2015; Loverro et al., 2015). Evidence suggests that as the weight of the load increases, the mobility of the individual, in terms of time to move a given distance and ability to complete an obstacle course, decreases (Carlton & Orr, 2014; Joseph, Wiley, Orr, Schram, & Dawes, 2018; Knapik et al., 2004; Lewinski et al., 2015; Loverro et al., 2015; Solomonson et al., 2016). Furthermore, as load increases, task performance (e.g., short sprints, agility runs, ladder climbs and negotiation of obstacle courses) are systematically decreased (Holewun & Lotens, 1992). Estimated decrements in performance of these tasks have about 1% decrease per kilogram of an additional load in male infantry soldiers (Holewun & Lotens, 1992).

Performance decrements while wearing body armor were investigated where participants wore three different types of body armor with associated weights of 4.8, 9.8 and 12.1 kg (Loverro et al., 2015). Participants completed a 30-m rush, unobstructed over ground walking (walk), walking over a 30-cm obstacle (walk over), and ducking under a shoulder height obstacle (walk under). These tasks were considered all relevant occupational tasks for military personnel. Researchers found average individual and total rush times were significantly longer (5% increase) with greater body armor weight. Furthermore, they found a potentially negative impact on trunk biomechanics during the walk and walk over tasks with restricted trunk flexion (13%) (Loverro et al., 2015). Similar results in rush times were found during an investigation by Hunt et al. (2016) simulating withdraw from enemy engagement (break contact) with five, 30-m sprints with five different loaded conditions (10- 30 kg) (Hunt, Tofari, Billing, & Silk, 2016). In addition to the 30-m sprints, the participants completed fire and movement simulations consisting of 16, 6-m bounds. Researchers observed statistical performance deterioration over the series (bounds or sprints) as well as with the increased deterioration with the heavier loads ($p < 0.01$). Hunt et al. (2016) concluded the first performance deterioration is due to decrements in initial acceleration and peak velocity (Hunt et al., 2016); similarly seen with sprint trials (9 kg load) (Lewinski et al., 2015). Maximal effort vertical jumps were observed with loads of 7.65

and 9 kg with 13% and 17 % decreases in performance due to the addition of the load, respectively (Dempsey, Handcock, & Rehrer, 2014; Lewinski et al., 2015). Performance decrements occur during sprints and rushes under various loads. Those decreases are more prevalent with heavier loads with their effect on acceleration and peak velocity; as well as the ability to generate power.

With these decrease in acceleration and ability to generate power, load carriage can also affect occupational task completion such as obstacle course. Researchers investigated the effects of load carriage during an obstacle course with special weapons and tactics (SWAT) operators carrying an average load of 14.2 kg and found time to completion between unloaded and loaded conditions increased by 7.8% (Thomas, Pohl, Shapiro, Keeler, & Abel, 2018). During the simulated tactical test, which consisted of 13 different tasks, 69% percent of the tasks were performed significantly slower in the loaded condition. Similarly, Solomonson et al. (2016) found a 17.7% decrease in critical speed with the addition of a 19 kg weighted vest during an all-out running test. In summary, load carriage affects occupational tasks to the point that tactical professionals see performance decrements and compromise survivability (Table 1).

Table 1

Summary of Acute Physiological and Biomechanical Effects of Load Carriage.

Author	Subjects	Task	Condition	Influence	Difference
Beekley et al. 2007	10 ♂	30-minute march at 6 km•h^{-1}	Loaded with 30%, 50% and 70% of BM	$\dot{V}O_2$, VE, and HR	17% ↑ $\dot{V}O_2$, 24% ↑ VE and 14% ↑HR between trials 30% to 50% and 50 % to 70%
Birrell et al. 2007	15 ♂	Walking	Trials of 8, 16, 24, 32 and 40kg	GRF parameters and Stance time	On average 30% ↑ in GRF parameters and 5% instance time from 8kg up to 40kg
Griffin et al. 2003	5 ♂ 5 ♀	Walking at 0.5, 1.0, 1.5 and 2.0 m/s^{-1}	Loaded with 0, 10, 20 and 30% BM	Metabolic Rate	In 30% loaded condition, net metabolic rate 47%↑
Lewinski et al. 2015	20 ♂	Sprint trials from four starting positions	With and without a 9.1kg weight belt	Stride velocity and acceleration	5% ↓ in stride velocity and 13% ↓ in acceleration
Phillips et al. 2016a	50 ♂	Maximal Treadmill Test	With and without 25 kg backpack	$\dot{V}O_{2peak}$, Exercise Time	11.1% ↓ $\dot{V}O_{2peak}$ 29.8% ↓ Exercise performance time
Phillips et al. 2016b	19 ♂	1.34 m/s^{-1} at 4% grade and Maximal Treadmill Test	0, 15, 30 and 45 kg and unloaded vs. 45kg	$\dot{V}O_2$, $\dot{V}O_{2peak}$, Power output (W), Duration, FVC and FEV_1	11.0, 14.5, 18 % ↑ $\dot{V}O_2$ between conditions (0, 15, 30, and 45kg), 10% ↓ $\dot{V}O_{2peak}$, 17% ↓W, 47% ↓ Duration between unloaded and 45kg, FVC and FEV_1 ↓ by 5.0 and 5.8%
Ricciardi et al. 2008	17 ♂ 17 ♀	Treadmill at a slow and moderate pace	Without and with body armor (BA)	$\dot{V}O_2$, HR, BL	At slow pace ↑11% $\dot{V}O_2$, ↑10% HR, and at moderate pace ↑15% $\dot{V}O_2$, ↑9% HR with ↑ 68% of BL levels with BA
Walker et al. 2015	22 ♂ 22 ♀	Maximal Treadmill Test	0, 10, 20 and 30 kg	FEV_1, FVC, MVV, $\dot{V}O_{2peak}$, HR_{peak}	From 0 to 30kg: 10% ↓FEV_1, 9% ↓ FVC, 12% ↓ MVV, 9% ↓ $\dot{V}O_{2peak}$, 4% ↓ HR_{peak}

BL= blood lactate, FVC= Forced vital capacity, FEV1= Forced expired volume in 1 second, GRF= Ground reaction force, HR= Heart rate, MVV= maximal voluntary ventilation, VE= ventilation, $\dot{V}O_{2peak}$= peak oxygen consumption, $\dot{V}O_2$= Oxygen consumption

2.3. Training Countermeasures for Performance Decrements with Load Carriage

2.3.1. Introduction

In 1987, the ADEA made recommendations to help reduce load carriage for soldiers (Agency, 1987). These five recommendations consisted of: (1) development of lighter weight components, (2) use of the soldier load-planning model, (3) development of specialized, load carrying equipment, (4) reevaluation of current doctrine that might affect load carriage, and (5) development of specialized physical training programs to increase load carriage capability. Since then, various investigations observed the effects of physical training programs on load carriage performances (Harman et al., 1997; Harman et al., 2008; Hendrickson et al., 2010; Jones & Hauschild, 2015; Knapik, Bahrke, Staab, Reynolds, & Vogel, 1990; Knapik, 1997; Knapik, Rieger, Palkoska, Camp, & Darakjy, 2009; Kraemer et al., 2001; Kraemer et al., 2004). The reason for this investigation is to understand and mitigate the performance decrements that occur from load carriage as previously discussed. The most common modes of physical training studied for load carriage include aerobic exercise, resistance training, and progressive load carriage. Studies that have combined resistance training with aerobic endurance training have seen larger effect sizes (0.81-1.69) of load carriage performance increases (Harman et al., 1997; Harman et al., 2008; Hendrickson et al., 2010; Knapik, 1997). Therefore, as a countermeasure to load carriage decrements, training programs should be combining aerobic training, resistance training and progressive load carriage.

2.3.2. Performance Measures and Exercise Prescription

Performance measures should be used with tactical professionals, just as they are with competitive sports athletes, to predict performance, prescribe exercise intensities, and to detect adaptations to the training stimulus. $\dot{V}O_{2max}$ is the most common performance measure of interest with tactical professionals, as many occupational tasks demands include cardiovascular challenges including foot pursuits and movements across the battlefield (Rayson, Holliman, & Belyavin, 2000). Conventional methods of evaluating aerobic capacity are in the laboratory setting with an incremental exercise test performed to exhaustion (Dicks, Jamnick, Murray, & Pettitt, 2016; George, Stone, & Burkett, 1997; Jackson et al., 1990; Jamnick, By, Pettitt, & Pettitt, 2016; Pettitt, Clark, Ebner, Sedgeman, & Murray, 2013). Lactate threshold (LT) is generally defined as the absolute workload above when blood lactate levels rise exponentially during incremental exercise due to a deficiency in oxygen during exercise (Brooks, 1986). The prescription of LT can be exclusive or as percentages of $\dot{V}O_{2max}$ to monitor training adaptations with load carriage (Brooks, 1986; Ricciardi et al., 2008; Simpson et al., 2017). More recently, critical velocity (CV) or speed associated with the maximal aerobic steady state has been used as a performance measure with tactical professionals (Fukuda, Smith, Kendall, Cramer, & Stout, 2012; Hoffman et al., 2016) in addition to being used to predict performance in astronauts on terrestrial missions (Ade et al., 2015).

Loaded time trials are also utilized as a method to assess load carriage performance (Faghy & Brown, 2014; Harman et al., 2008; Kraemer et al., 2004). The 2.4 km time trial has been used to evaluate performances with load carriage in the British Army (Brown et al., 2007; Brown et al., 2010) whereas the 3200 m time trial has also shown utility in evaluating load carriage performance with populations from the US Army (Harman et al., 2008; Kraemer et al., 2004). These methods allow the sports scientists working with tactical professionals the ability to detect adaptations to training stimulus specific to load carriage.

2.3.2.1. Aerobic Conditioning Measures for Load Carriage

Various training methods can achieve aerobic conditioning in the tactical professional. Prescription for aerobic training can be as a percentage of $\dot{V}O_{2max}$ or LT. For example, long-duration running can be done with progressive overload through increased running time up to an hour in most exercise programs (Harman, Gutekunst, Frykman, Nindl, et al., 2008; Hendrickson et al., 2010; Kraemer et al., 2004). These long-duration runs are typically conducted at an intensity between 70 and 80% of $\dot{V}O_{2max}$ and can be monitored through heart rate (Kraemer et al., 2004). Both of the previous studies also utilized interval training to challenge both anaerobic and aerobic energy systems with higher intensities prescribed on 80-100% of $\dot{V}O_{2max}$. The 30-15 Shuttle Test (Buchheit, 2008) was previously used with success in 287 police recruits in an academy setting conditioning program (Orr, Ford, & Stierli, 2016). This police recruit conditioning program was similar to the military ability-based training used to increase aerobic fitness (Harman et al., 2008; Knapik et al., 2006). Orr et al. (2016) prescribed seven weeks of interval training based on the results from the individuals' 30-15 shuttle test using the formula: Interval distance = running speed ($m \cdot s^{-1}$) × % of effort × duration of interval. Each run cycle consisted of a 10 s run interval followed by a 10 s rest interval alternating continuously for 6 min. The percentage of effort started at 90% progressed as well as the number of sets of run cycles. The intervention group significantly improved aerobic fitness measured by an increased number of completed of shuttles (13%) from the control group (7%) that conducted regular running over the seven weeks. The results of this study demonstrate the importance of the ability-based training from the aerobic measure for physical conditioning.

Recently, LT has been associated with load carriage performance in trained soldiers (Simpson et al., 2017). The authors investigated whether LT and running economy were performance predictors for the eight-mile backpack running performance in a field condition with loads ranging from 22-30% of the soldiers' body weight with the absolute load of 20 kg. They concluded that blood LT testing during simulated load carriage tasks should be used to monitor training adaptations and to predict performance (Simpson et al., 2017). However, the authors also conclude that when working with a large number of soldiers, the logistics and expertise required to perform these tests would be burdensome as these resources are generally not available to these populations.

Critical velocity as a measure with utility for load carriage. Solomonson et al. (2016) found that with the addition of a 19 kg weighted vest during an all-out running test, performances were highly dependent on CV and running economy (Solomonson et al., 2016). The all-out running test allows for testing a more significant number of participants with resources commonly available to this population (e.g., in/outdoor track, stopwatches). Thus, providing evidence in approaches using aerobic performance measures (with LT and CV) for training and performance increases with load carriage in tactical professionals.

2.3.2.2. Exercise Intensity Domains

Metabolic responses to constant work rate exercise has been described into specific exercise intensity domains: moderate, heavy, severe, and extreme (Figure 2). Moderate exercise includes the work rates below LT or gas exchange threshold (GET). Gas exchange threshold is the disproportional increase in carbon dioxide (CO_2) production relative to the O_2 utilized during skeletal muscle metabolism known as metabolic acidosis (Beaver, Wasserman, & Whipp, 1986). During moderate intensity, the O_2 uptake involves a rapid increase in O_2 consumption followed by a steady state usually attained within three minutes in healthy individuals (Burnley & Jones, 2007). This O_2 debt is a result of the constant requirement of adenosine triphosphate (ATP) where the immediate requirement for energy is met with phosphocreatine (PCr) (Gollnick, Piehl, & Saltin, 1974). Heavy exercise domain is similar to the moderate domain in the oxygen uptake response, differing with a slow component (due to the increased reliance on type II muscle fibers).

Additionally, in the heavy domain, time for O_2 to stabilize increases with intensity as approaching the upper boundary of the heavy domain and steady state is delayed by 10-20 minutes (Burnley & Jones, 2007). Contributing to the slow component is the recruitment of type II muscle fibers that are less efficient with oxygen utilization causing increased ventilation (Gaesser & Poole, 1996; Whipp, 1994). Between moderate intensity and heavy exercise lies the boundary of LT or GET. The next domain, severe exercise, there is no steady state achieved, and the amplitude of the slow component is more significant than with heavy exercise and fails to stabilize; results in the depletion of finite energy stores with the accumulation of fatiguing metabolites (e.g., H^+, ADP); continuing at this intensity results in attainment of $\dot{V}O_{2max}$. Demarcating the heavy and severe exercise domains of exercise is critical velocity/speed (CS) (Poole et al., 2016). In the extreme domain, there is no attainment of $\dot{V}O_{2max}$ because the exercise duration is too short (< 120 s). The lower boundary for the extreme domain is the highest power that will elicit $\dot{V}O_{2max}$.

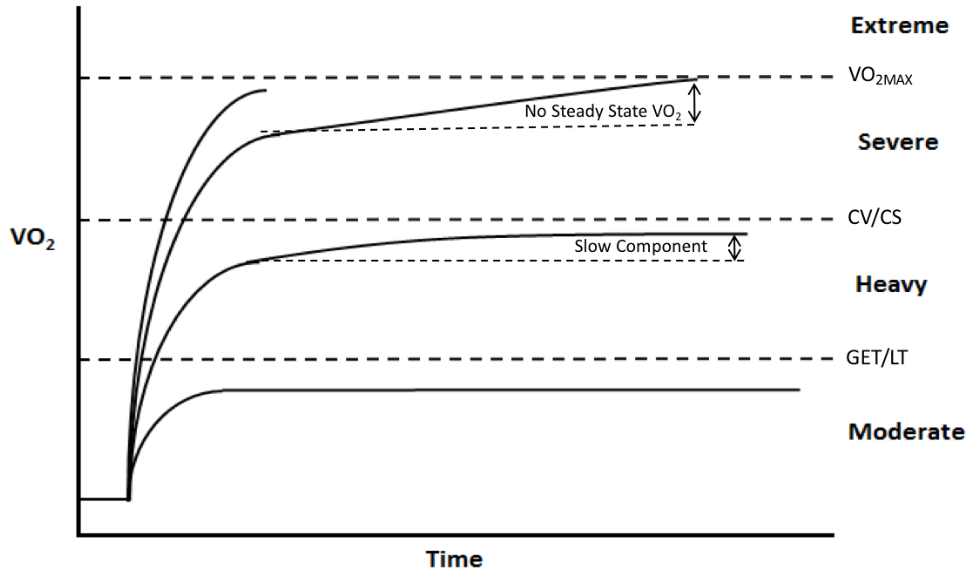

Figure 2. Domains of Exercise
Domains of Exercise depicted with oxygen uptake kinetics (Burnley & Jones, 2007). CS= critical speed, CV= Critical velocity, GET= gas exchange threshold, LT= lactate threshold, $\dot{V}O_2$= oxygen consumption

2.3.2.3. Critical Velocity Model

Critical power (CP) defined as the maximum rate power that can be maintained for a sustained time without fatigue on whole muscle (Monod & Scherrer, 1965). Critical power, synonymous with CV, is the heavy-severe exercise boundary that represents the highest work rate with a steady state; above that boundary results in $\dot{V}O_2$ rising until exhaustion with $\dot{V}O_{2max}$ attained (Gaesser & Poole, 1996; Poole, Ward, Gardner, & Whipp, 1988; Whipp, 1994). The finite capacity of work completed above CP (the curvature constant), is denoted as *W'* (n.b. pronounced W prime) (Burnley & Jones, 2007; Poole et al., 1988). Traditional methods of deriving CP and *W'* involved a series of time to exhaustion trials at various intensities relative to peak power from an incremental exercise test; the hyperbolic relationship between power output and time to exhaustion defined CP and *W'* (Fukuba et al., 2003; Hill, 1993; Monod & Scherrer, 1965). Similarly, CP or CV/CS for running determines mechanical measures associated with aerobic and anaerobic fitness, specifically the metrics of CV (aerobic) and the maximal capacity to displace the body (*D'*) at speeds above CV, expressed in meters (Pettitt et al., 2012). For example, if one's CV was 4.0 $m{\cdot}s^{-1}$ and *D'* was 200 m, that individual's capacity to sustain running speed of 5 $m{\cdot}s^{-1}$ (1 $m{\cdot}s^{-1}$ faster) would be for 200 m that would result in depleting their *D'* (200 m) (Jones, Vanhatalo, Burnley, Morton, & Poole, 2010a). The higher the *D'*, the longer distance the runner can travel at speeds exceeding CV; running performance are found to be dependent on both CV and *D'*.

The 3-minute all-out test (3MT) had been developed to estimate CP and *W'* for cycling (Burnley, Doust, & Vanhatalo, 2006), yielding reliable measures (Johnson, Sexton, Placek, Murray, & Pettitt, 2011; Wright, Bruce-Low, & Jobson, 2017). There have been various methods of prescribing the load for the 3MT for cycling originally by using the Δ 50% between $\dot{V}O_{2max}$ and GET gathered from a preliminary GXT (Vanhatalo, Doust, & Burnley, 2007). Subsequent efforts have been made to eliminate the need for the GXT by using a fixed percentage of BM (4.5%) (Bergstrom et al., 2012), various percentages (3%, 4%, and 5%) of BM based on self-reported activity level (Clark, Murray, & Pettitt, 2013), and using the self-report physical activity rating to calculate the load for the 3MT (Dicks et al., 2016). Procedures for the 3MT become less controversial when used with running, given participants are instructed to build up to the maximal speed progressively and maintain as fast of running speed as possible during the entire test (three minutes) (Pettitt et al., 2012). The timing of the 3MT has been completed using global positioning sensor technology (Pettitt et al., 2012), video recorded times on waypoints (Clark, West, et al., 2013), or manually recording split times at waypoints (Solomonson et al., 2016). During this all-out effort, the runner will presumably expend *D'* within 150 seconds, and CV will be mean speed during the last 30 seconds. The finite capacity to run above CV or (*D'*) is calculated from the average velocity during the first 150 seconds (V_{150s}), minus CV multiplied by the time (150s). To ensure the runner is not pacing the test, it has been suggested to calculate the slope of the last 30 seconds of the test, which is analogous with the asymptote from the speed time relationship and should equal 0 (Saari, Dicks, Hartman, & Pettitt, 2017).

The results from the running 3MT yield measures (CV and *D'*) can form individualized distance-time and speed-time curves that could be used to predicted race performances and even used for high intensity interval training (Burnley & Jones, 2007; Clark, West, et al., 2013; Jones et al., 2010a; Pettitt, 2016; Pettitt & Dicks, 2017; Pettitt et al., 2012). The running 3MT results have shown potential for prescribing intervals for sports teams (Clark, West, et al., 2013) and monitoring changes in endurance and high-intensity capacity (Pettitt, 2016). For use with tactical professionals, the 3MT was used to investigate the effects of load carriage on the CV and *D'* (Solomonson et al., 2016) and provided evidence of the utility of the 3MT to prescribe intervals (Pettitt & Dicks, 2017).

2.3.2.4. Anaerobic Training Measures for Load Carriage

Along with aerobic tasks, demands placed on the tactical professionals can be anaerobic with sprints, lifting, wall climbs, climbing stairwells and buddy carries (Harman et al., 2008; Kraemer & Szivak, 2012). Various methods of measuring anaerobic work capacity with rushes and sprints have been used in the literature to predict load carriage and military task performances (Bishop et al., 1999; Haisman, 1988; Harman et al., 2008; Knapik et al., 2004; Treloar & Billing, 2011). Other anaerobic measures such as the Wingate test (measuring peak power, mean power, and the ratio of percent decrease over the test duration) (Bouchard, Taylor, Simoneau, & Dulac, 1991) and vertical jump tests have been used to assess physiological determinants of performance in military tasks (Bishop et al., 1999; Harman et al., 2008; Knapik et al., 2004). Lower and upper body strength is also used as a variable when looking to improve performance in load carriage. The one repetition maximum (1RM) can be used to determine strength as well as to prescribe resistance training programs (Kraemer & Szivak, 2012). The use of the 3MT has utility in measuring finite capacity above CV in running (*D'*) (Pettitt et al., 2012), as an alternative for physical fitness tests in a military setting (Fukuda et al., 2012), and to predict performance in combat-specific tasks with Special Forces soldiers (Hoffman et al., 2016). A range of anaerobic training measures has been used to assess work capacities as determinants of performance in occupational performance tasks.

2.3.3. Interval Training for Load Carriage

Interval training has shown to be a time-efficient option in aerobic training strategy to stimulate a number of skeletal muscle adaptations that are comparable to traditional training methods (continuous exercise at 50-70% $\dot{V}O_{2max}$) (Burgomaster et al., 2008; Gibala & McGee, 2008). Intervals are often prescribed as a percentage of $\dot{V}O_{2max}$, maximal heart rate, objective measures of RPE (Billat, 2001). Due to the higher intensities, interval training requires a higher motivation to perform the vigorous exercise (Ekkekakis, Hall, & Petruzzello, 2005). As a method to increase load carriage, interval training has been prescribed to increase both aerobic and anaerobic energy systems using progressive overload with increasing repetitions, distances and decreasing rest time (Harman et al., 2008; Hendrickson et al., 2010). Interval training for load carriage can be conducted at 80-100 % of $\dot{V}O_{2max}$ and use work to rest ratios (W:R) that vary from 1:05 to 1:4 (Kraemer et al., 2004). An example of the work to rest ratio (1:05), a prescribed interval is two minutes, and the rest would be a one-minute interval, where a 1:4 work to rest ratio would allow for an 8-minute rest interval. These interval methods can evoke specific metabolic responses from the exercise prescription (e.g., increases in HR, $\dot{V}O_2$, and blood lactate levels). To enhance aerobic metabolism and performance, the bouts should last three to five minutes, which have been reported as optimal for evoking the most substantial gains in aerobic fitness (Coggan, Habash, Mendenhall, Swanson, & Kien, 1993; Hickson, Bomze, & Holloszy, 1977; Knuttgen, Nordesjo, Ollander, & Saltin, 1973). For optimal performance improvements with track and marathon runners, research suggests 20% of training volume be interval training (Enoksen, Tjelta, & Tjelta, 2011). The literature reports using 400, 800, 1200, and 1600 m runs conducted close to maximal intensity derived from a 3.2 km TT with a 1:1 recovery time during an 8-week training program (Hendrickson et al., 2010). Moreover, short sprints of 100 m to 200 m with 6 to 8 repetitions over nine-weeks (Knapik et al., 1990) and intervals of 100 to 400 m at 90 to 100 % of $\dot{V}O_{2max}$ over 12-weeks have also been found to help improve load carriage (Kraemer et al., 2004).

Interval training stimulates the activated receptor gamma peroxisome proliferator (PGC-1α) of the primary regulators of mitochondrial biogenesis in the skeletal muscle (Little & Cochran, 2011; Wright et al., 2007). These adaptation responses are complex and involve crosstalk of multiple intracellular signaling systems. With PGC-1α, mitochondrial networks are expanded and increase the maximal amount of ATP that can be generated via the electron transport chain during exercise (Little & Cochran, 2011; Wright et al., 2007). The increase in aerobic fitness is primarily due to the increase in cardiac output and peripheral O_2 extraction (Bassett & Howley, 2000). Contributions from interval training involve changes in stroke volume, blood volume, capillary density, and mitochondrial content with increases in aerobic fitness (Christensen et al., 2016; Helgerud et al., 2007; Levine, 2008). Interval training can result in a higher number and size of motor units recruited and increased the frequency of activation during training (Hendrickson et al., 2010). It has been suggested that interval training may promote neuromuscular adaptations, such as increased muscle activation and rate of force development (Hendrickson et al., 2010).

The CV concept has been used as an interval prescription method with collegiate level soccer players and demonstrated the ability to detect aerobic capacity increases (6%) from a two day/week four-week training program (Clark, West, et al., 2013). The advantage of using this model is prescribing intervals based on a percentage of *D'* and CV relative to individual's anaerobic and aerobic measures, respectively (Jones et al., 2010a) as opposed to conventional prescription methods as mentioned previously. More recently, using the CV concept has shown the plausibility of using this method to prescribe interval programming for training tactical professionals with load carriage (Solomonson et al., 2016). Solomonson et al. (2016) developed a regression equation to identify the relationship between the load carriage percent of body mass (15-25%) and decreases in CV. After completing an unloaded running 3MT, the regression equation could be used to prescribe interval training with an assigned amount of load carriage (15-25% body mass). In summary, programs involving properly prescribed interval training would decrease the effects load carriage has on running economy and velocity, thus improving the survivability of combat soldiers (Liew, Morris, Keogh, Appleby, & Netto, 2016). Table 2 displays the results of concurrent physical training studies with interval training to improve load carriage performance.

Table 2

Concurrent Studies with Interval Training to Improve Load Carriage Performance

Author	Subjects	Training Period (wks)	Load Carriage Task (distance, load)	Interval Training Method	Concurrent Training	Differences
Harman et al. 2008	32 ♂	8	3.2 km, 32 kg	Starting w/2-3 600-800 m progressing to 8-10 100-200 m	Compared two Periodized RT and SPF with RM 5d·wk^{-1}	15% ↑ RM Performance, 18% ↓ in 400 m run with 18 kg, 13% ↑ $\dot{V}O_{2max}$, 12%↑ Bench press and Squat
Hendrickson et al. 2010	56 ♀	8	3.2 km, 33 kg	1 d·wk^{-1} 200, 400, 800, 1600 m with 1:1 W:R using 3.2 km TT intensity	Compared 4 groups: Periodized UB and LB RT with AT and RM 3d·wk^{-1}	14 % ↑ RM Performance, 8% ↑ $\dot{V}O_{2max}$, 37% ↑ Squat, 10% ↓ 2-mile run time
Knapik et al. 1990	137 ♂	9	20 km, 46 kg	6 x 100 m progressing up to 8 x 200 m	Progressive RM, AT and RT program 5 d·wk^{-1}	Between the 4 groups: ↔ aerobic fitness, 2 x-month RM ↑ 12%
Knapik et al. 1996	13♀	14	5 km, 19 kg	4 x 400 m 15% over 2 mile time, 1:1.5-1:1 W:R	Periodized UB and LB RT with AT, No RM, 1hr per day 5 d·wk^{-1}	4% ↑ in RM performance, 9% ↑ in Est. $\dot{V}O_{2max}$, 16 % ↑ Floor to Chest Lift
Kraemer et al. 2004	35 ♂	12	3.2 km, 45 kg	400 to 800 m, with 1:4 to 1:0.5 W:R over 12-wk, 90-100% $\dot{V}O_{2max}$	Periodized RT and AT, No RM 4 d·wk^{-1}	Between 4 groups: 15% ↑ RM Performance 9% ↓ 2-mile run time, 9% ↑ Vertical Jump

AT= Aerobic Training, LB= Lower Body, UB= Upper Body, RT= Resistance Training, RM= Road March, SPF= Standardized Physical Training, W:R = Work to Rest Ratio, $\dot{V}O_{2max}$= Maximal Oxygen consumption

2.3.4. Concurrent Training for Load Carriage

Concurrent training involves training for more than one physiological response at a particular time (Hickson, 1980). The common types of concurrent training with tactical professionals are combined resistance and aerobic endurance training programs and are well-known methods to improve load carriage performance (Knapik et al., 2012; Orr et al., 2010). Military physical fitness programs also encompass concurrent training (Knapik et al., 2009). There have been some studies comparing different physical training programs to improve military performance that includes load carriage (Harman et al., 2008; Kraemer et al., 2004). With both endurance training programs and strength-power programs used simultaneously, there is an absence of compatibility in which type 1 muscle fibers make no changes with heavy resistance training and fail to see any improvement in anaerobic power (Kraemer & Szivak, 2012). Furthermore, when conducting concurrent training for load carriage, one must caution high levels of aerobic training (e.g., long duration runs) as it will compromise anaerobic and strength capabilities of the individual (Kraemer & Szivak, 2012). Indeed, the combination of both high-intensity endurance training and resistance training significantly improves load carriage performance (Kraemer et al., 2004).

Concurrent training programs offer an attractive approach to training individuals for load carriage due to the previously mentioned improvements. An 8-week program that consisted of weight training, running, interval training, agility drills and progressive load hikes, resulted in significant improvements in militarily relevant tasks (e.g., 3.2 km walk/run with 32 kg load, 400 m run with 18 kg load, 5 to 30-second rushes to and from prone position, 80 kg casualty drag, obstacle course) (Harman et al., 2008). Researchers observed increases in $\dot{V}O_{2max}$ (10-13%); as well as similar improvements in strength with the 1RM for bench and squat (10-12%). This investigation demonstrated a focus on strength development overpower offered duel benefits with increases in strength and aerobic capacity.

Hendrickson et al. (2010) tested program variables over 12 weeks on similar military relevant tasks as the previous investigation by Harman et al. The training groups consisted of aerobic endurance, strength training, combined training group, and control group. Hendrickson et al. (2010) observed the most significant improvement for each of the occupational tasks tested with the combined group (see Table 2). Additionally, the combined group showed similar improvements in aerobic capacity (7.6%) and muscular strength (37.6%) as did the aerobic endurance (6.2%) and strength training groups (46.3%), respectively. Between two different meta-analyses, substantial training effects were observed when combined training was conducted three times per week lasting at least four weeks (Knapik et al., 2012; Orr et al., 2010). In summary, the evidence suggests concurrent training as the standard for improving load carriage with a suitable balance between resistance and aerobic training.

2.3.5. Progressive Load Carriage

Progressive load carriage can be part of a training program where the speed and distance of the march and the weight of the load carried can be manipulated to improve load carriage performances (Knapik et al., 1990). Specificity is an essential concept to improving load carriage performance, where the training is relevant and appropriate for the desired effect (Hendrickson et al., 2010; Kraemer et al., 2001; Kraemer et al., 2004; Orr et al., 2010). Improvements in load carriage include progressive load carriage two to four times a month within physical training programs (Knapik et al., 1990; Knapik et al., 2012). When comparing two separate eight-week training programs, researchers incorporated an 8-km backpack hike with weight-based training (Harman et al., 2008). These hikes were performed at a speed of 6.4 km·h^{-}

[1]and lasted 75 min. The first hike was completed without load and each subsequent week the load was increased based on the performance of the participant to a maximum of 33 kg. In a timed 3.2 km, 32 kg load carriage trial, participants improved by reducing time to completion by 15 % after 8-week training. Among various physical training programs, the most significant improvement with load carriage was those that implemented once weekly progressive load carriage (Knapik et al., 2012; Williams et al., 2002).

When investigating the training doses of load carriage capacity, Visser et al. (2005) compared high intensity (35-67.5% of body mass) and low volume (4.1 to 5.5 km) compared to low intensity (20-40% of body mass) and high volume (8.3 to 16.5 km) where intensity was load and volume was distance. This study covered an eight-week training program with the training groups further broken down to once a week and once every two weeks for training dose combinations with load carriage. The load carriage speed was held constant at 5.5 $km \cdot h^{-1}$. The higher intensity group saw a greater percent improvement with both weekly and every two weeks, 17.9% and 9.1% respectively, compared to the low-intensity group, 7.3% and 5.7% respectively (Visser, van Dijk, Collee, & Van der Loo, 2005). The results suggest training improvement facilitated by intensity, frequency, and then by volume (Visser et al., 2005). As progressive load carriage focuses on the specific energy systems and muscles need to improve performance with load carriage as part of training programs.

2.3.6. Aerobic Blood Flow Restriction Exercise

Blood flow restriction (BFR) exercise is performed with the application of pressurized cuffs to the proximal portion of the extremity with the goal of maintaining arterial inflow while occluding venous return (Abe et al., 2006). This strategy of utilizing BFR with resistance training is that lighter loads (20-50% 1 RM) can be used to establish gains in muscular strength

(Madarame et al., 2008), hypertrophy (Abe et al., 2010), and muscular endurance (Takarada, Sato, & Ishii, 2002) that are similar to traditional high-load resistance training (≥70% 1RM) (Scott, Loenneke, Slattery, & Dascombe, 2016). For aerobic training exercise with BFR, such as cycling and walking, the intensity is similar to the lighter loads (using 20-40% of $\dot{V}O_{2max}$) (Abe et al., 2006; de Oliveira, Caputo, Corvino, & Denadai, 2016; Park et al., 2010). Blood flow restriction conducted with low-intensity aerobic exercise training (e.g., walking, cycling) has shown significant improvements in cardiac performance, metabolism and muscular strength simultaneously (Abe et al., 2010; de Oliveira et al., 2016; Park et al., 2010). Recent research has shown BFR exercise provides an insufficient stimulus to activate the signaling pathways governing mitochondrial and angiogenesis responses as observed with moderate- to high-intensity endurance exercise (Conceicao et al., 2016; Smiles et al., 2017). Some of the mechanisms that result from aerobic exercise BFR training that could be beneficial to load carriage include: 1) increased muscle recruitment during exercise (Takada et al., 2012), 2) increased duration of metabolic acidosis with the accumulation of waste products signaling hormonal responses (Burgomaster et al., 2003), 3) metabolic adaptations from changes in oxygen delivery (Downs et al., 2014) , and 4) improvements in endurance capacity (i.e., oxidative enzymes, capillary density, stroke volume, and decreased exercising HR) (Abe et al., 2010; Park et al., 2010). The combination of low-intensity aerobic exercise (e.g., walking, cycling) with BFR has been shown to be a single training method to bring on multiple benefits (e.g., strength, hypertrophy, increase in oxidative enzymes) (Abe et al., 2010; Abe et al., 2006), while also showing a significant increase in $\dot{V}O_{2max}$ (Abe et al., 2010; Park et al., 2010). This mode of aerobic exercise has shown to be beneficial with athletes (Park et al., 2010), older adults (Abe et al., 2010), even astronauts in preparation for microgravity environments (Hackney, Everett, Scott, & Ploutz-Snyder, 2012).

There have been various cuff pressures utilized in the research that vary from percentages of systolic blood pressure (e.g., 130% of SBP) (Hackney, Downs, & Ploutz-Snyder, 2016; Takada et al., 2012), progressive ranges 160-220 mmHg (Abe et al., 2006; Park et al., 2010), or a consistent pressure (180 mmHg) (Cook, Kilduff, & Beaven, 2014). With aerobic exercise such as walking or cycling, increasing pressure is commonly found during training: 120-160 mmHg (Renzi, Tanaka, & Sugawara, 2010), 140-200 mmHg (de Oliveira et al., 2016), and 160-230 mmHg (Park et al., 2010; Sakamaki, Bemben & Abe, 2011).

Blood flow restriction combined with walk training could be seen as a valuable method in training for load carriage. Walking with BFR has been researched for acute effects (Mendonca, Vaz, Teixeira, Gracio, & Pezarat-Correia, 2014; Renzi et al., 2010), as well during training studies (Abe et al., 2006; Park et al., 2010; Sakamaki et al., 2011). One significant acute effect observed during walk training with BFR was an overall increase in net $\dot{V}O_2$ (increasing submaximal $\dot{V}O_2$) (Mendonca et al., 2014). With the BFR, venous return and stroke volume (SV) was reduced due to the vascular resistance (Renzi et al., 2010). Heart rate also increases to maintain cardiac output (Renzi et al., 2010). In one training study with collegiate male basketball players, the athletes performed a two-week walk training program (two sessions/day, six $d \cdot wk^{-1}$; in total 24 sessions) (Park et al., 2010). Each of the sessions consisted of five bouts of three minutes of walking (4 $km \cdot h^{-1}$ at 5% grade) with one-minute rest on a motorized treadmill with increasing cuff pressure starting at 150 mmHg to 220 mmHg. The total duration of cuff inflation was approximately 22 min with three minutes before the start of exercise. Park et al. (2010) found an increase in $\dot{V}O_{2max}$ by 11.6% and an increase in anaerobic capacity mean power on Wingate by 2.5%. They also observed increases in SV and decreased HR at sub-maximal work rates. However, the athletes did see increases in their resting systolic blood pressures by 10.8% that might have been caused by the continued decreases in arterial compliance from the frequency of the BFR training (Renzi et al., 2010). BFR exercise shows empirical support as a plausible method of training or rehabilitation for the tactical professional with load carriage. To date, no reports of acute or training studies using BFR combined with walking and load carriage exist.

2.4. Injuries Associated with Load Carriage and Safety Considerations

2.4.1. Introduction

Musculoskeletal injuries, just like in sport, can adversely affect tactical professionals' mobility and can also reduce the readiness and effectiveness of a unit or organization (Nindl et al., 2013; Orr et al., 2015). The heavy loads carried by these professionals lead to an increase in fatigue, altered mechanics, and elevate stress on the musculoskeletal system (Harman et al., 2001; Hauschild, Roy, Grier, Schuh, & Jones, 2016; Knapik et al., 2004; Orr et al., 2010). The incidence rate of acute injuries (e.g., blisters, metatarsalgia) with load carriage has been reported as high as 50% but reduced through proper equipment, adjustment of equipment, load shifting and footwear (Knapik et al., 2004). These injuries are commonly attributed to the higher braking forces while carrying the backpack in addition to the load weight (Knapik, 1997). However, injuries to the lower back and lower limbs pose significant issues with the addition of load carriage (Hauschild et al., 2016). Even added weight as low as eight kg can begin to increase injury risk to the lower back (Roy, Lopez, & Piva, 2013). Roy et al. (2013) found that significant predictors for lower back injury included age, fitness score, previous history of lower back pain, equipment weight, and time spent wearing body armor. While investigating a brigade combat team of 800 soldiers over a one-year deployment, lower back pain (LBP) incidence rate was 77%. Best predictors for experiencing LBP during a 12-month deployment were older age, lower fitness scores, more time spent wearing body armor, and heavier equipment worn (Roy et al., 2013).

In light of the aforementioned predictors of injury, there is supporting evidence to the idea that exercise conditioning programs may mitigate injuries associated with load carriage (Carlton & Orr, 2014; Nindl et al., 2013). It appears the most common risk factor for injury is low-entry level fitness (Andersen, Grimshaw, Kelso, & Bentley, 2016). However, even with exercise conditioning programs, there are some risks, such as overuse injuries similarly observed in runners (Hreljac, 2004), and possible injuries from exercise training methods, such as the addition of BFR, can occur not following proper safety precautions (Loenneke, Wilson, Wilson, Pujol, & Bemben, 2011).

2.4.2. Musculoskeletal and Overuse Injuries with Load Carriage

Musculoskeletal injuries account for 31% of medical evacuation and treatment for military, non-battle related injuries on deployments (Nindl et al., 2013). There is a higher risk of injury when deployed soldiers and police officers wear load carriage for four hours or more (Dempsey et al., 2013; Roy et al., 2013). The majority of the anatomical locations where these injuries occur include the back, knees, feet, and shoulders (Knapik, 2014; Knapik et al., 2004; Orr et al., 2015). Due to the requirement for military personnel to wear load carriage equipment and continuous deployments of 6 to 12 months without adequate recovery periods, overuse injuries are also prominent (Knapik et al., 2012). Knapik et al. (2012) observed outpatient injuries before and after deployments of two different combat units to Iraq and Afghanistan for 3,496 soldiers. The injuries classified in five different categories focused on training-related injury, overuse injuries and a comprehensive injury index. Both units showed overall increases in post-deployment injuries. More importantly, those soldiers with pre-deployment injuries were 1.4 to 3 times more likely to experience post-deployment injuries (Knapik et al., 2012).

Just as with non-tactical athletes, training frequency can follow a u-shape in injury risk: too few and too many training sessions per week had a similar associated risk (Figure 3) (Hreljac, 2004; Roos, Taube, Zuest, Clenin, & Wyss, 2015). When exploring the training of junior elite orienteering athletes, those that include higher frequencies of HIT sessions suffer fewer or less severe injuries (Roos et al., 2015). The authors concluded the use of HIT session in comparison to all running training sessions could prevent running-related injuries by decreasing the volume of training and chance for overuse injuries (Roos et al., 2015). Injuries can arise from an abrupt increase in load carriage, mileage, or intensity with unconditioned tactical professionals properly conditioned. These injuries can continue 1 to 15 days post activity (Knapik, 2014) or more severely lead to limited duty restrictions of 30-60 days (Schuh-Renner et al., 2017). Thus, following gradual increases in speed, distance, and weight for load carriage activities is recommended to reduce injury (Army, 2017). This volume increase is suggested to be around 10% and gradually progressing these variables (e.g., speed, distance, weight) over 2-6 months depending on the level of fitness and unit activities (Hauschild et al., 2016).

Figure 3. Associated Training Load and Injury Risk
Relationship with an associated training load (AU) and injury Risk (Hreljac, 2004; Roos et al., 2015). AU= Arbitrary units based on the physical fitness of the individual

2.4.2.1. Back Injuries

In a meta-analysis conducted by Orr and colleagues (2015), researchers found that of the total number of injuries reported by Australian Service members, the leading individual site of injury was the back (23%). In a self-report injury survey of over 800 soldiers, it was found that 29% of the soldiers attributed their back pain to wearing their body armor four hours or more during their deployment versus the other group that wore their body armor less than four hours (Konitzer, Fargo, Brininger, & Reed, 2008). As loads increase from protective gear and mission requirements, so can the risk for lower back injuries as the increase in torque that back muscles must resist (Knapik et al., 2004). Lower back injuries can be difficult to define as they can range from localized pain of spinal discs, connecting ligaments, nerves and supporting muscles (Knapik, 2014). Heavy loads seem to be the leading cause for back pain with load carriage. As these heavy loads cause changes in trunk angles, and cyclic lumber compression and shear forces cause stress on the muscle and ligament of the back and spine (Knapik, 2014; Orr et al., 2015). It is recommended to distribute the weight more evenly around the trunk to reduce the changes in forward trunk angles (Knapik, 2014). It is also suggested that increasing overall core strength (back, abdomen, hips) can assist in the prevention of back injuries from load carriage (Knapik et al., 2012). The use of proper progression in the fitness training program can also assist in the prevention of back injury as well as increase load carriage capacity (Hauschild et al., 2016).

2.4.2.2. Lower Extremities

With the increases of impact forces, due to the addition of load carriage, tactical professionals are at a higher risk of injury to the lower extremities (e.g., legs, knees, and feet) (Knapik, 2014; Orr et al., 2015; Orr, Pope, Johnston, & Coyle, 2014). Foot blisters are the most prevalent (~50%) in lower extremity injuries with load carriage (Knapik, Reynolds, Staab, Vogel, & Jones, 1992). Wearing the proper shoe size, moisture wicking socks, antiperspirants, and prior foot conditioning to load carriage can assist in decreasing incident rates of foot blisters (Knapik, 2014). Metatarsalgia, an overuse injury in the ball of the foot affecting the heads of the metatarsals, is usually associated with rapid increases with the intensity of weight-bearing activities such as load carriage (Knapik, 2014; Knapik et al., 2004). Although the incidence rates are low with acute training, metatarsalgia can become more pronounced with long durations of load carriage.

Lower extremity stress fractures are a more severe injury that are associated with chronic loading of the bones during activity (Knapik et al., 2004). The additional stress placed on bones causes them to become weakened, before the bones can adapt to the additional stress, they fracture (Knapik et al., 2004). Common sites for stress fractures with load carriage are the tibia and metatarsals due to their weight bearing roles in gait (Knapik, 2014). Stress fractures can be a significant injury to the tactical professionals due to the extended recovery period for bone remodeling (Knapik et al., 2004). Lower extremity injuries can be debilitating to the tactical professional; thus, best practices in prevention and conditioning methods should be utilized.

2.4.3. Injury Prevention and Rehabilitation

Ideally, attempts should be made to decrease the percentage of body weight carried to reduce load carriage related injuries. Since this is not always operationally feasible, reducing the cumulative overloading from both physical training and occupational tasks may help prevent injury (Schuh-Renner et al., 2017). Research suggests more specific, individualized, and tailored physical training for each tactical professionals' need (Orr et al., 2010). Specific and tailored physical training could suggest a mutually supporting training regime with load carriage training as part of concurrent physical training to improve aerobic fitness, muscular strength, and muscular endurance (Army, 2012; Knapik et al., 2012; Orr et al., 2010). Furthermore, training should focus less on distance and emphasize higher intensity (speeds and weight carried) (Knapik et al., 2012; Orr et al., 2010; Visser et al., 2005). With the combination of accumulated distance marched and increased the weight of the load carried, there is an increase for injury risk during road marching as seen with training load (Schuh-Renner et al., 2017). Aerobic and muscular endurance have been found to protect against common military injuries (Schuh-Renner et al., 2017). Although, this higher intensity training should balance with proper progression and recovery, particular importance should be placed on distance and frequency balanced with the other activities that will place repetitive stress on lower-extremities. In summary, exercise training programs should balance load carriage, aerobic training, resistance training, muscle strength, muscular endurance, agility and mobility drills with proper periodization and progression for performance and reduction for injury risk (Army, 2012).

Blood flow restriction exercise has been incorporated into general exercise as well as in rehabilitation practices (Hughes, Paton, Rosenblatt, Gissane, & Patterson, 2017; Ladlow et al., 2017; Patterson & Brandner, 2018). Patterson and Brandener (2018) found that approximately 24% of practitioners surveyed utilized BFR with patients during rehabilitation from injury. Ladlow et al. (2017) designed a protocol with low-intensity resistance training combined with BFR during bilateral leg press and knee extension exercises, at 30% of participants predicted 1RM, as an intervention technique with lower limb injuries as a feasibility study with armed forces personnel. Based on the outcome measures researchers suggest the feasibility with the use of BFR as part of a practical rehabilitation program (Ladlow et al., 2017). Blood flow restriction exercise can also be used with tactical professionals and athletes who may not be able to tolerate training with high loads for various reasons but may benefit from low-load training with BFR (Scott et al., 2016). Blood flow restriction can also be used to reduce post-operative disuse atrophy after anterior cruciate ligament surgery as well as low-load training methods to build strength during recovery (Loenneke, Young, Wilson, & Andersen, 2013). Investigators proposed progressive training models using BFR in rehabilitation as well as with high load training (Loenneke et al., 2012). To date, no studies have reported using walking BFR and load carriage as a rehabilitative methodology.

2.4.4. Safety Considerations

In order to best protect tactical professionals, preparing them for the rigors of load carriage has been successfully demonstrated (Orr et al., 2010). The weight of the load carried, how often, the speed carried, and the duration are all considerations for the development of concurrent physical training programs with load carriage (Knapik et al., 2012). Additionally, investigating new methods for training or rehabilitative practices, such as BFR exercise, understanding the contraindications and associated risk are essential to implementing safe training (Loenneke et al., 2011).

2.4.4.1. Load Carriage and Exercise

Recommendations for the elements of training program parameters to decrease injury risk with load carriage are as follows: 1) keeping loads between 30-45% of body mass (Knapik, 2014), 2) two to four long distance load carriage marches per month (Knapik et al., 2012), 3) gradual progression (Jones & Hauschild, 2015), and 4) use terrain to keep low stress on the body (Knapik, 2014). It is essential to include load carriage for specificity in training so tactical professionals are more prepared for the additional stress of operating under load carriage (O'Neal, Hornsby, & Kelleran, 2014). Current US Army recommendations for load carriage include: maximum weights in a combat situation or fighting loads to be 30% of body mass and 45% for that includes approach march equipment to last until resupply (Army, 2017). However, in attempts to reduce the risk of injury with load carriage, recent research suggests reducing the amount of weight carried to no more than 25% of one’s body mass (Schuh-Renner et al., 2017). As previously mentioned, distance, speed, and weight should follow increases of no more than 10% with progression over 2 to 6 months (Army, 2017; Hauschild et al., 2016; Jones & Hauschild, 2015). Lastly, the terrain can be an additional risk when it comes to load carriage (Knapik, 2014). The type of terrain such as steep rocky hills, sand and snow increases perceived exertion and energy cost. Because of the increased energy cost, fatigue can impact stress on the body and increase the risk of injury (Knapik, 2014). Just as with any exercise, proper warm-up and cool-down should be conducted to decrease injury risk (Army, 2012).

2.4.4.2. Blood Flow Restriction

Many reviews concerning potential safety issues with BFR exercise conclude the risks are indifferent from traditional high-intensity exercise in healthy, active adults (Heitkamp, 2015; Loenneke et al., 2011; Scott et al., 2016). Contraindication for BFR training includes a history of deep vein thrombosis, cancer, open fracture, severe hypertension, stroke, diabetes, current inflection, acidosis, spinal cord injury, rhabdomyolysis, compromised circulation or peripheral vascular system (Biscontini, 2017; Heitkamp, 2015). In a survey investigating the use of BFR by practitioners, researchers reported the following side effect incident rates: delayed onset muscle soreness (39.2%), numbness (18.5%), fainting/dizziness (14.6%) and bruising (13.1%) (Patterson & Brandner, 2018). Physical discomfort due to delayed onset muscle soreness from BFR exercise is expected but is reported to be mild (Umbel et al., 2009). Numbness and lightheadedness are possible; however, these side effects are highly transient and rapidly shift back to pre-exercise levels (Patterson & Brandner, 2018). Skin irritation from the BFR cuff is possible and can be minimized by wearing exercise spandex/work out attire or doubled layered sleeves under the cuff. Bruising can be related to the inflation pressure of the cuff (Patterson & Brandner, 2018). Cardiovascular responses such as blood pressure and heart rate changes due to BFR are similar to hemodynamic responses to traditional high-intensity training. These changes include significant increases in heart rate, systolic blood pressure, and mean arterial pressure compared to a resting value (Park et al., 2010). Due to the restriction of blood flow back to the heart, heart rate needs to increase to match with cardiac output (HR × SV) (Renzi et al., 2010). The risk for venous thrombosis and hypercoagulability with BFR exercise have been comprehensively evaluated and don’t appear to increase with low-intensity blood flow restriction in healthy adults (Loenneke et al., 2011). The BFR exercise devices such as Kaatsu (Kaatsu

Master, Toyko, Japan) and Delphi (Owens Recovery Science, San Antonio, TX, USA) have manufacturer guidelines for application and several safety measures such as timers, to ensure that participants are not under occlusion for excessive durations of time.

2.5. Conclusion

Tactical professionals, such as military, law enforcement, and fire and rescue personnel, require specialized equipment (load carriage) to complete their occupational demands and secure their physical safety (i.e., survivability). To decrease the effects load carriage has on job performance requires specialized conditioning programs that involve concurrent training with progressive load carriage. Critical velocity can be used as a performance measure with tactical professionals for both fitness testing and performance task predictions. Building aerobic capacity and running economy with interval training from the CV model is an appealing training method for tactical professionals. Other training methods such as BFR has been seen as possible methods with rehabilitation from injuries to prepare them for the rigors of load carriage in return to duty situations. Such physical training programs not only may increase performance but survivability of these tactical professionals. As aerobic and muscular endurance have been found to protect against common injuries associated with load carriage. The implementation of these training programs requires proper safety precautions that result in a time efficient, safe training methodology to increase performance in load carriage.

3. METHODOLOGY

Tactical professionals, such as military, law enforcement, and fire and rescue personnel, require specialized equipment to complete their occupational demands and secure their physical safety (i.e., survivability). This load carriage tends to limit the mobility and efficiency of tactical professionals through increased energy cost and perceptual effort to complete occupational tasks/demands (Dempsey et al., 2013; Notley et al., 2015; Ricciardi et al., 2008; Walker et al., 2015). In order to augment performance, specialized conditioning programs have been implemented to compensate for the load carriage concerns (Harman et al., 1997; Hendrickson et al., 2010; Pawlak et al., 2015; Williams et al., 2002). As part of concurrent training, HIT has led to improvements in load carriage performance as well as occupational specific tasks.

The 3-minute all-out test (3MT) provides estimates of critical velocity (CV), the maximal aerobic steady-state, and the maximal capacity to displace the body at speeds above CV (*D'*) (Burnley & Jones, 2007). The CV concept has been used as an interval prescription with collegiate level soccer players and demonstrated the ability to detect an increase (6%) in aerobic capacity after a two day/week 4-week training program (Clark, West, et al., 2013). The advantage of using this model is prescribing intervals based on a percentage of *D'* and CV relative to the individual's anaerobic and aerobic measures, respectively (Jones et al., 2010a). CV has been associated with technical and combat-specific performance measures in an elite special forces unit (Hoffman et al., 2016).

Recently, the CV concept has shown plausibility for use in prescribing interval training for tactical professionals using load carriage (Solomonson et al., 2016). Solomonson et al. (2016) developed a regression equation to identify the relationship between load carriage as a percent of body mass (15-25%) and decreases in CV. After completing an unloaded running 3MT, the regression equation could be used to prescribe interval training with an assigned amount of load carriage (15-25% body mass). Thus, a model of HIT prescribed using the CV concept to increase CV correctly would be of considerable use for improving tactical performance through decreasing the effects of load carriage on running economy and velocity (Liew et al., 2016).

In recent years, blood flow restriction (BFR) has become a novel accessory for various exercise training modes (Hackney et al., 2012). BFR is typically performed applying pressurized cuffs to the proximal portion of the extremity to maintain arterial inflow while occluding venous return (Abe et al., 2006). BFR exercise training at lower intensities has demonstrated gains in muscular strength, (Hackney et al., 2016) muscular endurance (Takarada et al., 2002), and cardiorespiratory endurance (Park et al., 2010). Furthermore, BFR conducted with low-intensity aerobic exercise (e.g., walking, cycling) has shown significant improvements in cardiac performance, metabolism, and muscular strength (de Oliveira et al., 2016; Park et al., 2010). This research shows empirical support as a plausible method to training or rehabilitation of tactical professionals with load carriage.

3.1. Investigation 1: Acute Responses to Leg Blood Flow Restriction during Walking Intervals with Load Carriage

The first purpose of this study was to compare the metabolic and perceptual responses with load carriage while walking with and without BFR. Based on the selected methodology, this was a within-subject, cross-over design study. Currently, there is limited literature on the use of BFR as a method to train with load carriage.

The following question guided the research:

What are the differences in cardiovascular, metabolic, and perceptual responses when walking with load carriage compared to walking with load carriage and blood flow restriction?

3.1.1. Participants

For investigation one, a volunteer sample of 12, healthy males were recruited for participation. This sample size was chosen based on an ANOVA A priori power analysis (Erdfelder, Faul, & Buchner, 1996). Recruitment of participants occurred through flyers and word of mouth. The participants were recreationally active as defined by completing both aerobic and resistance training two to five days per week for at least the past six months. Additionally, the participants were familiar or had experience with load carriage either through duty gear, body armor or backpack wear.

3.1.2. Documentation

Before the start of data collection, the Institutional Review Board at North Dakota State University approved this study (#HE18106). After completion of the Physical Activity Readiness Questionnaire (PAR-Q), Health History Questionnaire and providing written informed consent, participants were able to engage in the study. Researchers reviewed completed PAR-Qs and Health History Questionnaires to determine if subjects were healthy and capable of participating in the study. Participants were excluded from the study if: 1) they did not meet the required physical activity criteria; 2) they had any previous injuries in their neck, back or legs; 3) they were taking any medications for high blood pressure/hypertension; 4) if determined they have any known or significant signs of cardiovascular, pulmonary, metabolic disease or have two or more major coronary risk factors, or other reasons needing a medical clearance from the Health

History Questionnaire. Additional exclusions include: those with a prior ligamentous, bony, or other soft tissue reconstruction to the lower-extremity; a history of DVT; endothelial dysfunction; peripheral vascular disease (narrowing or blockage in a blood vessel); diabetes, acute fracture, tumor, or infection, individuals who are active smokers, have asthma, an implanted medical device, or the inability to consent. Participants had their risk factor for DVT assessed using the DVT Risk Assessment tool; excluded were those above low risk. With height and weight measurements, individuals with BMI of 30 $kg{\cdot}m^2$ or greater, classified as obese, were excluded from the study. Participants were excluded with systolic >130 mmHg or diastolic >80 mmHg blood pressure before either visit. Data collection occurred in the Human Performance Laboratory at North Dakota State University, 1301 Centennial Blvd., Fargo, ND 58102.

3.1.3. Procedures

Participants completed two testing sessions: 1) walking BFR familiarization (BFR) and 2) loaded walking without BFR (LOAD) and loaded walking with BFR (BFR-LOAD). The two sessions were 24 hours apart as well as the Load and BFR-Load conditions were counterbalanced to avoid an order effect. During the first visit, researchers measured anthropometric variables (height, weight) and blood pressure. Blood pressure (BP) was assessed five minutes before and after exercise testing using a manual sphygmomanometer cuff and stethoscope. Then there was a familiarization period with the Kaatsu leg cuffs by conducting a Kaatsu (pressure) cycle.

The participant conducted a walking session with the Kaatsu device while breathing into a two-way non-re-breathing valve connected to the metabolic cart and wore a heart rate monitor. The walking protocol included five sets of three-minutes walking at 4.8 $km{\cdot}h^{-1}$ with zero percent grade with 1-minute rest in which the treadmill was stopped. The pressure cuffs remained inflated for a total of 19 minutes, which is consistent with the walking BFR literature (Abe et al., 2006; Mendonca et al., 2014; Park et al., 2010). Once they completed the walking protocol, the research assistant familiarized the participant with the weight vest and the muscle oxygen sensor for the second session.

The participants completed the second session in a counterbalanced fashion to avoid an order effect with both walking with load carriage (LOAD) as well as walking with load carriage and BFR (BFR-LOAD). Resting BP and HR was taken after five minutes of sitting. Before the BFR session, participants underwent a Kaastu cycle as described earlier. The participants' visit consisted of 1) walking protocol with load carriage followed by a 20-min recovery, performed Kaatsu cycle, ended with the walking protocol with load carriage and BFR; or 2) Kaatsu cycle, walking protocol with load carriage and BFR followed by a 20-min recovery, ended with walking protocol with load carriage (Figure 4).

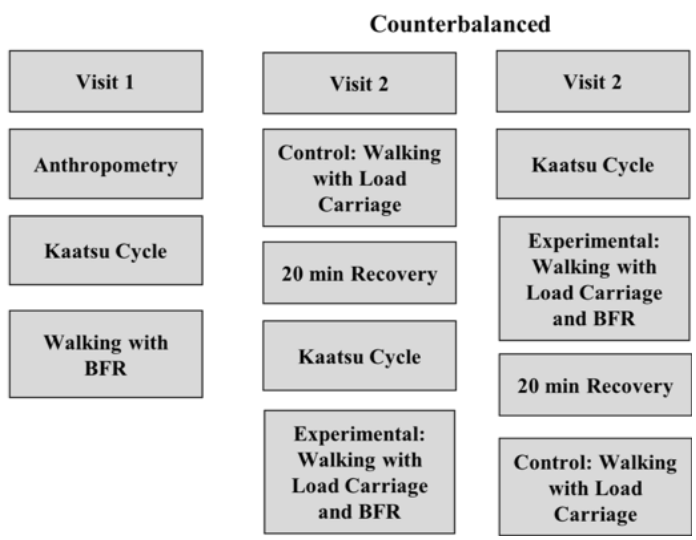

Figure 4. Experimental Design for Acute Responses to Leg Blood Flow Restriction during Walking Intervals with Load Carriage

3.1.4. Measures

3.1.4.1. Walking Protocols

The walking protocols used are similar to those previously used in the literature (Abe et al., 2006; Park et al., 2010). In brief, the protocol for all conditions consisted of five sets of 3-minute walking (4.82 $km \cdot h^{-1}$ at 0% grade) intervals on a motorized treadmill and a 1-minute rest between walking sets (19 minutes of total time). Walking speed and grade remained consistent during all conditions.

3.1.4.2. Blood Flow Restriction

Blood flow restriction was conducted through compression cuff control by the Kaatsu device (Kaatsu Nano, Sato Sports Plaza, Tokyo, Japan). Before the Kaatsu walk training, a specially designed cuff (50 mm wide) was placed around the most proximal portion of each leg. The cuff contains a pneumatic bag along its inner surface that was connected to an electronic air pressure control system to monitor the restriction pressure. During the first visit, participants were familiarized with the Kaatsu leg cuffs by conducting a Kaatsu (pressure) cycle with the device. The Kaatsu cycle involved eight rounds of cuff inflation for 20 seconds followed by five seconds of deflation. The Kaatsu cycle begins at inflation of 30 Standard Kaatsu Units (SKU), which is equivalent to 30 mmHg. After the five seconds of deflation, the cuff pressure will increase by 20 SKU for each subsequent round, ending at 100 SKU. Next, the researcher found the optimal SKU for exercise by measuring the individual's capillary refill time (CRT), or the time in seconds taken for the color to return to an external capillary bed. CRT was checked by applying pressure to the quadriceps, just above the knee, to cause blanching during cuff inflation. A CRT of three seconds indicated optimal SKU for exercise. Cuff pressure was continually increased by 10 SKU for 20 seconds, followed by a 5-second rest, until optimal SKU was reached (on average around 160 SKU). As a safety measure, our laboratory has used 1.3 times the resting systolic blood pressure as an upper limit to the pressure. Therefore, resting blood pressure from 110-139 mmHg would result in a range of 143-180 SKU (synonymous with mmHg) as the upper limit of applied cuff pressure.

For both experimental trials, the final belt pressure (training pressure) was individualized based on capillary refill per the Kaatsu user manual or the safety measure of 1.3 times systolic, which is a customized pressure based on participants' resting blood pressure. Restriction of leg muscle blood flow lasted for the entire exercise session, that included the one-minute rest periods (total of 19 min). The belt pressure was released immediately upon completion of the session.

3.1.4.3. Volume of Oxygen Consumption

A metabolic analyzer (Parvo Medics, Logan, UT) was used to measure O_2 consumption ($\dot{V}O_2$) and carbon dioxide (CO_2) production. Participants wore a nose clip and expired through a two-way rebreathing valve connected to the metabolic cart. Telemetry HR recorded simultaneously (Polar Electro Inc., Lake Success, NY), and all data was evaluated using 15 second averaging. Filter replacement and calibration between tests were performed according to the manufacturer's guidelines.

3.1.4.4. Muscle Oxygenation

Muscle oxygen was measured using a non-invasive monitor (MOXY, Hutchinson, MN) (Crum, O'Connor, Van Loo, Valckx, & Stannard, 2017). Placement of the monitor was on the vastus lateralis of the left leg. The sensor continuously monitored muscle oxygen saturation during both sessions using near-infrared spectroscopy.

3.1.4.5. Feeling Scale

Participants had the Feeling Scale (FS) (Hardy & Rejeski, 1989) explained to them by the researcher before engaging in the exercise test. During exercise testing, the FS (-5 to +5) assessment (Figure 5) was conducted at baseline as well as 15 seconds prior to the end of the third and fifth interval during the walking protocol. The researcher evaluated the individual's subjective overall feeling of affect along with objective measures (i.e., $\dot{V}O_2$, and heart rate).

−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5
Very		Bad		Fairly	Neutral	Fairly		Good		Very

Figure 5. Feeling Scale
(Hardy & Rejeski, 1989)

3.1.4.6. Physical Activity Rating Scale

Participants self-reported their current level of physical fitness over the previous six months on a 0-15 scale (Table 3) (Dicks et al., 2016). This Physical Activity-Rating (PA-R) was used to estimate participants' maximal oxygen uptake ($\dot{V}O_{2max}$) using the following non-exercising regression equation (George et al., 1997; Jackson et al., 1990):

$$\text{Est. } \dot{V}O_{2max}\,(\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = (56.363) + (1.921\times \text{PA-R}) - (0.381 \times \text{Age}) - (0.754 \times \text{BMI}) + (10.987 \times \text{Gender}, 1{=}\text{M}, 0{=}\text{F}).$$

Table 3

Physical Activity-Rating Scale

Select the number that **best describes** your overall level of physical activity for the previous **6 months.**	
Moderate Activity: golf, horseback riding, calisthenics, table tennis, bowling, weight lifting, yard work, cleaning house, walking for exercise	
Vigorous Activity: running or jogging, lap swimming, cycling, rowing, aerobics, skipping rope, running in place, or engaging in vigorous aerobic-type activity such as soccer, basketball, tennis, racquetball, or handball	
0: Sedentary	Avoid walking or exertion e.g., always use elevator, drive when possible instead of walking
1: Light activity	Walk for pleasure, routine use stairs, occasionally exercise sufficiently to cause heavying breathing and perspiration.
2: Moderate activity	10 to 60 minutes per week of moderate activity
3: Moderate activity	Spend over 1 hour per week of activity as described above
4: Vigorous activity	Spend less than 30 minutes a week of vigorous exercise
5: Vigorous activity	Spend 30 minutes to less than 60 minutes per week
6: Vigorous activity	Spend 1 hour to 3 hours per week
7: Vigorous activity	Spend 3 hours to 6 hours per week
8: Vigorous activity	Spend 6 hours to 7 hours per week
9: Vigorous activity	Spend 7 hours to 8 hours per week
10: Vigorous activity	Spend 8 hours to 9 hours per week
11: Vigorous activity	Spend 9 hours to 10 hours per week
12: Vigorous activity	Spend 10 hours to 11 hours per week
13: Vigorous activity	Spend 11 hours to 12 hours per week
14: Vigorous activity	Spend 12 hours to 13 hours per week
15: Vigorous activity	Spend 13 hours or more per week

(Dicks et al., 2016)

3.1.5. Statistical Analysis

All statistical analyses were conducted using SPSS 24 software (IBM Corp., Armonk, NY). Statistical significance was set at the 0.05 level of confidence. Separate repeated measures analysis of variance was used to analyze $\dot{V}O_2$, HR, and FS variables among the conditions. When an interaction effect was discovered post hoc testing using Bonferroni or equivalent corrections was applied.

3.2. Investigation 2: Applying the Critical Velocity Model to Increase Performance Markers and Load Carriage

The purpose of this study was to evaluate the effects of using the critical velocity (CV) model to prescribe two separate high-intensity interval training (HIT) regiments aimed at enhancing CV and load carriage performance. This research will add to the literature on the utility of the 3MT and the use of CV for individually customized training for tactical professionals. The novelty of the study derives from the ability to use the CV model to prescribe HIT with the goal to improve CV. With this increase in CV, we hypothesize that there will be a decrease in the effects that load carriage has on running economy and velocity, thus improving occupational performance.

The following question guided the research:

How will two different HIT regiments with load carriage affect performance and physiological variables?

3.2.1. Participants

For study two, twenty healthy adults were recruited for participation. The sample size is similar to a previous training study using CV derived HIT (Clark, West, et al., 2013). Recruitment of participants occurred through an informational meeting held in Army ROTC classes. The participants were recreationally active as defined by completing both aerobic and resistance training two to five days per week for at least the past six months. Additionally, the participants were familiar or had experience with load carriage either through body armor, backpack wear or both.

3.2.2. Documentation

Before the start of data collection, the Institutional Review Board at North Dakota State University approved this study (#HE18245). Participants completed the Physical Activity Readiness Questionnaire (PAR-Q), Health History Questionnaire, DXA screening form and provided written informed consent. Researchers reviewed completed PAR-Qs and Health History Questionnaires to determine if subjects were healthy and capable of participating in the study. Participants were excluded from the study if: 1) they did not meet the required physical activity criteria; 2) they had had any previous injuries in their neck, back or legs; 3) they were taking any medications for high blood pressure/hypertension; 4) if determined they have any known or major signs of cardiovascular, pulmonary, metabolic disease or have two or more major coronary risk factors, or other reasons needing a medical clearance from the Health History Questionnaire. Data collection occurred in the Human Performance Laboratory at North Dakota State University, 1301 Centennial Blvd., Fargo, ND 58102 and at the Shelly Ellig Indoor Track, 1625 14th Street North, Fargo, ND 58102.

3.2.3. Procedures

A quasi-experimental design, two groups with counterbalanced male and female participants, completed HIT intervals over a four-week period. The groups complete pre-testing measures during week one with anthropometric measurements including body composition, running 3MT, muscle strength and endurance tests, 400 m and 3200 m load carriage tasks. The HIT group (n = 10) participated in two interval sessions per week for four weeks (eight sessions). The Load Carriage HIT (LCHIT) group (n = 10) also complete the same HIT training (eight sessions); however, one of the weekly sessions (four in total) consisted of HIT with load carriage

(15-24% of their body mass) (See Figure 6). After attaining the participants' CV and *D'*, each participant's specific interval velocity was calculated. Interval speed was assigned:

$$Vt = [(D' \text{ x } 0.60)/ t_{LIM}] + CV, \quad (3.1)$$

where *Vt* is, the interval velocity and time limit (t_{LIM}) would be the interval time in seconds. Both groups started with a 180-second interval depleting 60% of *D'*. The intensity of the intervals will be evolving with velocity week by week. The LCHIT groups' CV adjustment for their intervals will be adjusted using the following equation (Solomonson et al., 2016):

$$\text{Adjusted CV} = \text{Original CV} + (-0.0638 \text{ x } \%\text{Load}) + 0.6982. \quad (3.2)$$

The starting point for load carriage was 15% of the participant's body mass. The interval workouts were conducted on a calibrated treadmill. The conversion of treadmill speed and grade was determined from the table published in previous literature (Pettitt et al., 2012). After the four weeks, the groups completed the same testing measures as done in week 1 with body composition, muscle strength and endurance tests, running 3MT, 400 m and 3200 m load carriage tasks.

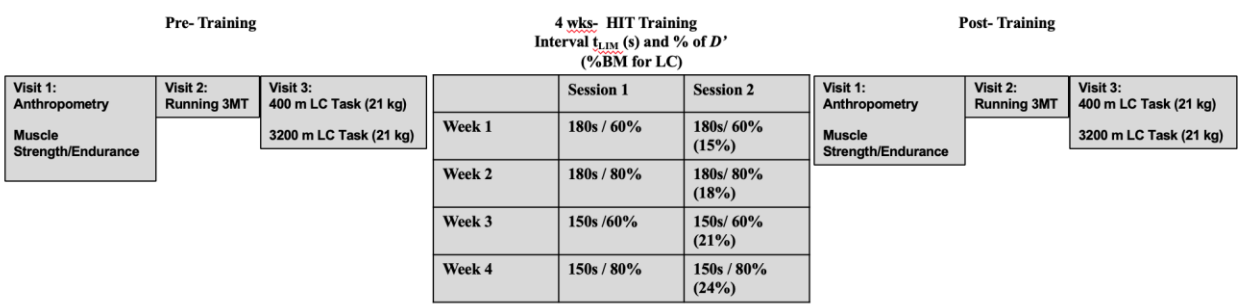

Figure 6. Experimental Design for Applying the Critical Velocity Model to Increase Performance Markers and Load Carriage

3.2.4. Measures

3.2.4.1. Body Composition

Body composition was evaluated using a dual-energy X-ray absorption (DXA) via a GE Healthcare Lunar Prodigy, Model #8915 bone densitometer. All females took a pregnancy test before the scan to ensure the participant's safety. Each scan took five to ten minutes and had minimum radiation exposure. Researchers ensured participants were wearing appropriate clothing (athletic shorts and t-shirt) for the scan and asked participants to remove any metal or other objects that may interfere with the scan. Data include regional body fat percentage, total mass, fat mass and lean mass.

3.2.4.2. Muscle Strength and Endurance

Muscle function of the upper right leg was assessed using a Biodex Pro4 System dynamometer (Biodex Medical Systems, Shirley, NY, US). The participants were seated in an upright position and moved the knee joint through flexion and extension at angular velocities of 60 and 180 degrees·second^{-1}, to examine the isokinetic strength and endurance of the knee flexors and extensors, respectively. Muscle strength testing included three maximal effort repetitions to determine peak torque (N·m) during extension. Muscle endurance test consisted of 21 maximal effort repetitions to assess total work (J). Participants were given a practice prior to each test.

3.2.4.3. Running 3-Minute All-Out Exercise Test (3MT)

Participants completed the running 3MT on an indoor 200 m running track. After 10 minutes of active warm-ups and dynamic stretches, participants were fitted with a watch (V800, Polar, Finland), telemetry heart rate monitor (H7, Polar, Finland), and a tri-axial accelerometry foot pod (Styrd, Boulder, CO, USA) sampling at 1 Hz. Participants were instructed to run an all-out maximal effort throughout the duration of the test. Researchers provided verbal encouragement throughout the test but did not provide elapsed time or time remaining to deter pacing. Data were downloaded from the commercial software by the watch manufacture and exported to Microsoft Excel (v16) (Microsoft, Redmond, WA, USA) for analysis. The running 3MT allowed researchers to estimate critical velocity (CV) (aerobic capacity) and the running capacities at speeds exceeding CV (*D'*). Critical velocity was measured as an average speed during the last 30 seconds of the test. Finite capacity to operate above CV (*D'*) was calculated from the average velocity during the first 150 seconds (V_{150s}) with the following equation (Pettitt et al., 2012):

$$D' = 150s\,(V_{150s} - CV). \tag{3.3}$$

Also, the $v\dot{V}O_{2max}$ was calculated as the speed value ($m \cdot s^{-1}$) 90 second into the test (Pettitt et al., 2012).

3.2.4.4. Interval Prescription

Critical velocity and *D'* measurements were used to prescribe intervals with and without load carriage. Using a prescription depleting 60% of *D'* as an example interval, the equations are as follows:

$$Vt = [(D' \times 0.60)/\, t_{LIM}] + CV, \tag{3.4}$$

where Vt is, the interval velocity and t_{LIM} would be the interval time in seconds.

For example, a participant's results from the 3MT yielded CV= 4.25 $m \cdot s^{-1}$and *D'* = 112.5 meters.

$$Vt = [(112.5 \times 0.60)/180] + 4.25$$

$$Vt = 4.63\ m \cdot s^{-1}$$

The participant will complete four intervals of 3 minutes running on a treadmill at 3.98 $m \cdot s^{-1}$ with 4 % grade with a 1:1 work: rest ratio (3 minutes rest). A speed limit of 3.98 $m \cdot s^{-1}$ (8.9 mph) was imposed to avoid changes to running form and to prevent any accidents on the treadmill belt.

LCHIT Intervals with 60% Depletion *D'* for 3 min (180s) =

Example participant with 15% of BM for load carriage Equation 2:

$$\text{Adjusted CV} = 4.25 + (-0.0638 \times 15\%) + 0.6982$$

$$\text{Adjusted CV} = 3.99\ m \cdot s^{-1}$$

The participant will complete four intervals of 3 minutes running on a treadmill at 3.98 $m \cdot s^{-1}$ at 0% grade with 15% of BM for load carriage with a 1:1 work: rest ratio (3 minutes rest).

3.2.4.5. Load Carriage Tasks

Each participant completed two load carriage tasks: 1) 400 m and 2) 3200 m, both with 21 kg as the load. The participant wore an adjustable, weighted, short-waist vest to replicate load carriage (VMax Weightvest.com, Rexburg, ID, USA). The vest was fitted and adjusted for comfort before testing. Participants will complete the 400 m or 2 laps around the track as fast as possible. Participants were provided no less than a 10 min break prior to completing the 3200 m or 16 laps around the indoor track as quickly as possible. During the break, participants removed the weighted vest and were encouraged to hydrate and rest.

3.2.5. Statistical Analysis

All statistical analyses were conducted using SPSS (version 24). Statistical significance was set at the 0.05 level of confidence. The following analyses were used to answer the research question: How will two different HIT regiments with load carriage affect performance and physiological variables? Separate group (HIT vs. LCHIT) by time (pretesting vs. post-testing) factorial analysis of variance will assess the differences in CV ($m \cdot s^{-1}$), *D'* (m), the velocity at

$\dot{V}O_{2max}$ ($m \cdot s^{-1}$), peak force (N·m), total work (J), time to completion for load carriage tasks (min and s), percent body fat, percent lean mass and total body mass (kg). Partial Eta Squared (η^2) was used to detect effect size of the independent variables within the model. Independent sample T-tests were used for comparison of demographic data between the groups. Post hoc effect size (ES) differences from pre to post measures were done using Cohen's d (mean difference divided by pooled SD) (Cohen, 1988). Where the scale for interpretation is as follows: less than 0.1 = trivial effect, 0.1-0.3 = small effect, 0.3-0.5 = moderate effect and greater than 0.5 = large effect.

3.3. Conclusion

Tactical professionals require specialized equipment and protection to complete their occupational demands and protect their physical safety. This specialized equipment and protection limit the mobility and efficiency of tactical professionals through increased energy cost and perceptual effort to complete occupational tasks. To decrease the effects load carriage has on job performance, tactical professionals should implement specialized conditioning programs that involve concurrent training. One potential program can use CV as a performance measure for both fitness testing and performance task predictions. Building aerobic capacity and running economy with interval training from the CV model has been observed with high utility for tactical professionals. Other training methods such as BFR have been recognized as methods for rehabilitation from injuries to prepare them for the rigors of load carriage in returning to duty. Aerobic fitness and muscular endurance have been found to protect tactical professionals against common injuries associated with load carriage. Such physical training programs may increase not only performance but also survivability of these tactical professionals. The implementation of these training programs along with proper safety precautions should be used to provide a time-efficient, safe-training methodology to increase occupational performance under load.

4. COMPARABLE METABOLIC RESPONSES FROM BLOOD FLOW RESTRICTION WALKING AND WALKING WITH LOAD: IMPLICATIONS FOR RECONDITIONING

4.1. Abstract

Load carriage is an inherent part of the military and other tactical occupations (e.g., law enforcement, firefighters). Load carriage can range from 10 to 60 kg and may lead to a higher risk for back and leg injuries. Exercise with blood flow restriction is a form of low-intensity exercise that can elicit gains in muscular strength and aerobic endurance capacity. The purpose of this study was to compare the acute metabolic and perceptual responses from low-intensity blood flow restriction walking to waking with load carriage. **Methods:** Twelve male participants (21.8 $\pm$ 1.5 yrs, mass 84.4 $\pm$ 11.1 kg, height = 181.3 $\pm$ 7.2 cm) underwent five bouts of 3-min treadmill walking at 4.8 $km \cdot h^{-1}$ with 1-min rest interval under three different conditions: blood flow restriction walking (BFR), loaded with 15% of their body mass (LOAD) and loaded walking with blood flow restriction (BFR-LOAD). **Results:** $\dot{V}O_2$ increased 7% during the BFR-LOAD (p = .001) compared with BFR or LOAD alone. There were no differences in $\dot{V}O_2$ between BFR and LOAD (p = .202). BFR-LOAD showed significantly lower muscle oxygen saturation (SmO_2) (p = .044) and deoxygenated hemoglobin (DeOxyHb) (p = .047) compared to LOAD. There was no condition effect (p = .459) but there was a time effect (p = .004) for feeling scale. **Conclusion**: There was an increased metabolic response with the addition of BFR-LOAD. Notably, there was no significant difference between walking with BFR and walking with only load carriage. Based on our results, we suggest there is potential for BFR to decrease the use of load carriage for individuals engaging in rehabilitation and reconditioning programs due to injury.

4.2. Introduction

Tactical professionals (i.e., military, firefighters, law enforcement) are often faced with load carriage as a fundamental problem in their occupational environments. Load carriage takes the form of duty gear, equipment, weapons, body armor, and protective gear (Dennison et al., 2012; Knapik et al., 2004; Loverro et al., 2015; Ricciardi et al., 2008). Within the tactical professional population, load carriage can range from 7 kg to 60 kg depending on specific occupations and operations conducted (Dean, 2008; Dempsey et al., 2013; Ricciardi et al., 2008). Military operations in remote combat locations often burden service members with an average load of 30 kg in the modern combat battlefield (Dean & DuPont, 2003). Similarly, law enforcement and firefighters work with fatiguing ranges of load carriage from 7-25 kg while performing various physically demanding occupational tasks (Dennison et al., 2012; Ricciardi et al., 2008).

Musculoskeletal injuries account for 31% of medical evacuations and treatment for military, non-battle related injuries on deployments (Nindl et al., 2013). Similarly, there is a higher risk of injury when deployed soldiers and police officers wear load carriage for four hours or more (Dempsey et al., 2013; Roy et al., 2013). Due to the requirement for military personnel to wear load carriage equipment and continuous deployments of 6 to 12 months without adequate recovery periods, overuse injuries are also prominent (Knapik et al., 2012). Ideally, attempts should be made to decrease the percentage of body mass carried to reduce load carriage related injuries. Since this is not always operationally feasible, reducing the cumulative overloading from both physical training and occupational tasks may help prevent injury (Schuh-Renner et al., 2017). Research suggests more specific, individualized, and tailored physical training for each tactical professionals is needed (Orr et al., 2010). Specific and tailored physical training could suggest a mutually supporting training regime with load carriage training as part of concurrent physical training to improve aerobic fitness, muscular strength, and muscular endurance (Army, 2012; Knapik et al., 2012; Orr et al., 2010).

The load carriage endured by these professionals has also been found to alter biomechanical functionality (Knapik et al., 2004; Loverro et al., 2015), which could be placing them at higher risk for musculoskeletal injury. Injuries just like in sport, can adversely affect tactical professionals' mobility and could also reduce the readiness and effectiveness of a unit or organization (Nindl et al., 2013; Orr et al., 2015). The combination of accumulated duration of wear, distance traveled, and increased weight carried, leads to an increased injury risk as observed with higher training load with athletes (Schuh-Renner et al., 2017). Injuries to the lower back and lower limbs pose significant issues during load carriage. Thus, the use of a low-intensity training method to rehabilitate military personnel or slowly accustom them to additional loading requirement is warranted.

Recently, blood flow restriction (BFR) has become a novel accessory for various exercise training modes (Hackney et al., 2012). Blood flow restriction is performed through the application of pressurized cuffs to the proximal portion of the extremity with the aim of maintaining arterial inflow while occluding venous return (Abe et al., 2006). For aerobic training exercise with BFR, such as cycling and walking, the intensity is similar to the lighter loads (using 20-40% of $\dot{V}O_{2max}$) (Abe et al., 2006; de Oliveira et al., 2016; Park et al., 2010). BFR conducted with low-intensity aerobic exercise training (e.g., walking, cycling) has shown significant improvements in cardiac performance, metabolism and muscular strength simultaneously (Abe et al., 2010; de Oliveira et al., 2016; Park et al., 2010). In a BFR training study with collegiate male basketball players, the athletes performed a two-week walking low-intensity interval training (LIT) program (two sessions/day, six days/week; in total 24 sessions) and investigators found an increase in $\dot{V}O_{2max}$ by 11.6% (Park et al., 2010). These data show empirical support as a plausible method of training for tactical professionals, especially if performing the training with load carriage. Therefore, the purpose of this study was to compare the metabolic and perceptual responses with load carriage while walking with and without BFR.

4.3. Methods

4.3.1. Participants

A sample of 12 healthy males (mean ± SD, age = 21.8 ± 1.5 yrs, height = 181.3 ± 7.2 cm, mass 84.4 ± 11.1 kg, and body mass index (BMI) 25.6 ± 2.6 $kg \cdot m^2$) completed this study (Table 4). The participants were recreationally active as defined by completing both aerobic and resistance training two to five days per week for at least the past six months based on reported PA-R level (Table 3, Ch 3). The participant engaged in 360-420 minutes of vigorous activity a week with an estimated $\dot{V}O_{2max}$ of 55.29 ± 4.15 $ml \cdot kg^{-1} \cdot min^{-1}$. Additionally, the participants were familiar or had experience with load carriage either through duty gear, body armor or backpack wear.

Table 4

Demographic Data: Blood Flow Restriction and Load Carriage

Demographics	Mean ± SD
Age (yrs)	21.8 ± 1.5
Height (cm)	181.3 ± 7.2
Body Mass (kg)	84.4 ± 11.1
Weight Vest Load (kg)	12.7 ± 1.6
Thigh Circumference (cm)	59.3 ± 4.8
Exercise Cuff Pressure (mmHg)	156.3 ± 4.9
PA-R (0-15 Scale)	8.1 ± 2.1
Weight vest with 15% of Body Mass (kg)	12.7 ± 1.6

PA-R= Physical Activity-Rating

4.3.2. Documentation

Before the start of data collection, the Institutional Review Board at North Dakota State University approved this study. After completion of the Physical Activity Readiness Questionnaire (PAR-Q), Health History Questionnaire and providing written informed consent, participants were able to engage in the study. Participants were excluded from the study if: 1) they did not meet the required physical activity criteria; 2) they had any previous injuries in their neck, back or legs; 3) they were taking any medications for high blood pressure/hypertension; 4) if determined they had any known or major signs of cardiovascular, pulmonary, metabolic disease or have two or more major coronary risk factors, or other reasons needing a medical clearance from the Health History Questionnaire. Additional exclusions included: those with a prior ligamentous, bony, or other soft tissue reconstruction to the lower-extremity, a history of deep venous thrombosis (DVT), endothelial dysfunction, peripheral vascular disease (narrowing or blockage in a blood vessel), diabetes, acute fracture, tumor, or infection, individuals who are active smokers, have asthma, an implanted medical device, or the inability to consent. Participants had their risk factor for DVT assessed using the DVT Risk Assessment tool (Caprini, 2005), excluding those above low risk. Participants had their blood pressure assessed and were exluded if their systolic >130 mmHg and/or diastolic >80 mmHg before either visit. Researchers collected height using a portable stadiometer (Seco Corp, Model 213, Hamburg, Germany) and body mass measurements with a digital scale (Denver, Instruments, Model DA 150, Bohemia , New York), individuals with BMI of 30 $kg \cdot m^2$ or higher, classified as obese, were excluded from the study.

4.3.3. Measures

4.3.3.1. Walking Protocols

The walking protocols used were similar to those previously used in the literature (Abe et al., 2006; Park et al., 2010). In brief, the protocol for all conditions comprised of five sets of 3-minute walking (4.8 km·h^{-1} at 0% grade) intervals on a motorized treadmill and a 1-minute rest between walking sets (19 minutes of total time). Walking speed and grade remained consistent during all conditions.

4.3.3.2. Blood Flow Restriction

Researchers conducted BFR through compression cuff controlled by the Kaatsu device (Kaatsu Nano, Sato Sports Plaza, Tokyo, Japan). Before the Kaatsu walk training, a specially designed cuff (50 mm wide) was placed around the most proximal portion of each leg. The cuff contained a pneumatic bag along its inner surface that was connected to an electronic air pressure control system to monitor the restriction pressure. During the first visit, researchers familiarized participants with the Kaatsu leg cuffs by conducting a Kaatsu (pressure) cycle with the device. The Kaatsu cycle involved eight rounds of cuff inflation for 20 seconds followed by five seconds of deflation. The Kaatsu cycle started inflation of 30 Standard Kaatsu Units (SKU) which was approximately equivalent to 30 mmHg. After the five seconds of deflation, the cuff pressure was increased by 20 SKU for each subsequent round, ending at 100 SKU. Next, the researcher found the optimal SKU for exercise by measuring the individual's capillary refill time (CRT), or the time in seconds taken for the color to return to an external capillary bed. CRT was checked by applying pressure to the quadriceps, just above the knee, to cause blanching during cuff inflation. A CRT of approximately three seconds indicated optimal SKU for exercise. Cuff pressure was continually increased by 10 SKU for 20 seconds, followed by a 5-second rest, until optimal SKU was reached (on average around 160 SKU). As a safety measure, our laboratory used 1.3 times the resting systolic blood pressure as an upper limit to the pressure (Downs et al., 2014; Hackney et al., 2016). Therefore, resting blood pressure from 110-139 mmHg would result in a range of 143-180 SKU (synonymous with mmHg) as the upper limit of applied cuff pressure. For both experimental trials, the final belt pressure (training pressure) was individualized based on capillary refill per the Kaatsu user manual or the safety measure of 1.3 times systolic, which is a customized pressure based on participants' resting blood pressure. Restriction of leg muscle blood flow lasted for the entire exercise session, which included the one-minute rest periods (total of 19 min). The cuff pressure was released immediately upon completion of the session.

4.3.3.3. Volume of Oxygen Consumption

A metabolic analyzer (Parvo Medics, Logan, UT) was used to measure O_2 consumption ($\dot{V}O_2$) and carbon dioxide (CO_2) production. Participants wore a nose clip and expired through a two-way rebreathing valve connected to the metabolic cart. Heart rate by telemetry was recorded simultaneously (Polar Electro Inc., Lake Success, NY), and all data were evaluated using 15 second averaging. Researchers performed filter replacement, and calibration between tests according to the manufacturer's guidelines.

4.3.3.4. Muscle Oxygenation

Muscle oxygen was measured using a non-invasive monitor (MOXY, Hutchinson, MN) (Crum et al., 2017). Placement of the monitor was on the vastus lateralis of the left leg. The sensor continuously monitored muscle oxygen saturation (SmO_2), total hemoglobin (THb), oxygenated hemoglobin (OxyHb) and deoxygenated hemoglobin (DeoxyHb) during both sessions (LOAD and BFR-LOAD) using near-infrared spectroscopy.

4.3.3.5. Feeling Scale

Participants had the Feeling Scale (FS) (Hardy & Rejeski, 1989) explained to them by the researcher before engaging in the exercise test. During exercise testing, the FS (-5 to +5) assessment (Figure 5, Ch 3) was conducted at baseline as well as 15 seconds before the end of the third and fifth interval during the walking protocol. The researcher evaluated the individual's subjective overall feeling of affect along with objective measures (i.e., $\dot{V}O_2$, and heart rate).

4.3.3.6. Physical Activity Rating Scale

Participants self-reported their current level of physical fitness over the previous six months on a 0-15 scale (Dicks et al., 2016). This physical activity rating was used to estimate participants' maximal oxygen uptake ($\dot{V}O_{2max}$) using the following non-exercising regression equation (George et al., 1997; Jackson et al., 1990):

$$\text{Est. } \dot{V}O_{2max}\,(\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = (56.363) + (1.921 \times \text{PA-R}) - (0.381 \times \text{Age}) - (0.754 \times \text{BMI}) + (10.987 \times \text{Gender, 1=M, 0= F}).$$

4.3.4. Procedures

Participants completed three testing sessions: 1) walking with BFR familiarization (BFR) and 2) loaded walking without BFR (LOAD) and 3) loaded walking with BFR (BFR-LOAD). The first session was just BFR and the second session was LOAD and BFR-LOAD. The two sessions were 24 hours apart as well as the LOAD and BFR-LOAD conditions were counterbalanced to avoid an order effect. During the first visit, researchers measured anthropometric variables such as height, body mass, and blood pressure. Blood pressure was measured five minutes before and after exercise testing using a manual sphygmomanometer cuff (Diagnostix 703, American Diagnostic Corp., Hauppauge, NY, USA) and stethoscope (Adscope

601, American Diagnostic Corp., Hauppauge, NY, USA). There was a familiarization period with the Kaatsu leg cuffs by conducting a Kaatsu (pressure) cycle.

The participant conducted a walking session with the Kaatsu device while breathing into a two-way non-re-breathing valve connected to the metabolic cart and wore a heart rate monitor. The walking protocol included five sets of three-minutes walking at 4.8 $km \cdot h^{-1}$ with zero percent grade with 1-minute rest in which the research stopped the treadmill. The pressure cuffs remained inflated for a total of 19 minutes, which is consistent with the walking BFR literature (Abe et al., 2006; Mendonca et al., 2014; Park et al., 2010). Once they completed the walking protocol, the research assistant familiarized the participant with the weight vest and the muscle oxygen sensor for the next session.

The participants' visit consisted of 1) walking protocol with load carriage followed by a 20-min recovery, performed Kaatsu cycle, ended with the walking protocol with load carriage and BFR; or 2) Kaatsu cycle, walking protocol with load carriage and BFR followed by a 20-min recovery, ended with walking protocol with load carriage (Figure 4, Ch 3).

4.3.5. Statistical Analysis

All statistical analyses were performed using SPSS version 24 (IBM, Armonk, NY). In the event of missing data, pairwise deletion was used in the statistics. Descriptive statistics are reported as mean $\pm$ SD. Statistical significance was set at the 0.05 level of confidence. Separate repeated measures analysis of variance (ANOVA) (exercise $\times$ time) were used to analyze $\dot{V}O_2$, and heart rate between the LOAD, BFR-LOAD and BFR only conditions. Peak $\dot{V}O_2$ and HR were measured through all exercise sets and recovery $\dot{V}O_2$, and HR was measured through all rest periods. Muscle oxygen saturation data collected during the trials were averaged across all exercise sets and all rest periods A separate (exercise $\times$ time) repeated measures ANOVA was conducted comparing SmO_2, THb, OxyHB, and DeOxyHb between LOAD and BFR-LOAD at exercise and during rest. A separate repeated measures ANOVA was conducted comparing the FS between the LOAD and BFR-LOAD condition and the baseline, third and fifth interval. Paired sample t-test was used to compare the FS between the intervals. Statistical significance was determined by $p < 0.05$. When a significant F statistic was found, post hoc testing using Bonferroni corrections were performed.

4.4. Results

There was no significant exercise condition × time effect, F (8, 88) = 1.569, p = .146, η^2 = .125 or time effect for $\dot{V}O_2$ F(4, 44) = 0.526, p = .717, η^2 = .046. However, there was a significant exercise condition effect for $\dot{V}O_2$, F(2, 22) = 21.683, p < .001, η^2 = .663. Bonferroni corrected pairwise comparisons indicated significantly greater $\dot{V}O_2$ in the BFR-LOAD versus LOAD (p < 0.01), but no differences between BFR and LOAD (p = 0.202) (Figure 7). There were no significant exercise condition × time effects for HR, F(8, 88) = .238, p = .983, η^2 = .021 condition effects, F(2, 22) = .851, p = .440, η^2 = .072, or time effects, F(4, 44) = 1.601, p = .191, η^2 = .127 (see Table 5).

Table 5

Heart Rate during Walking Intervals

Condition	Interval 1	Interval 2	Interval 3	Interval 4	Interval 5
LOAD	99.7 ± 10.9	99.1 ± 11.2	99.8 ± 11.6	100.3 ± 10.7	99.6 ± 12.7
BFR-LOAD	101.7 ± 8.4	100.3 ± 10.2	101.2 ± 10.7	101.9 ± 11.2	102.0 ± 10.9
BFR	99.2 ± 11.0	97.75 ± 11.5	98.3 ± 10.3	99.5 ± 11.1	98.8 ± 10.1

Mean ± SD, BPM= Beats Per Minute

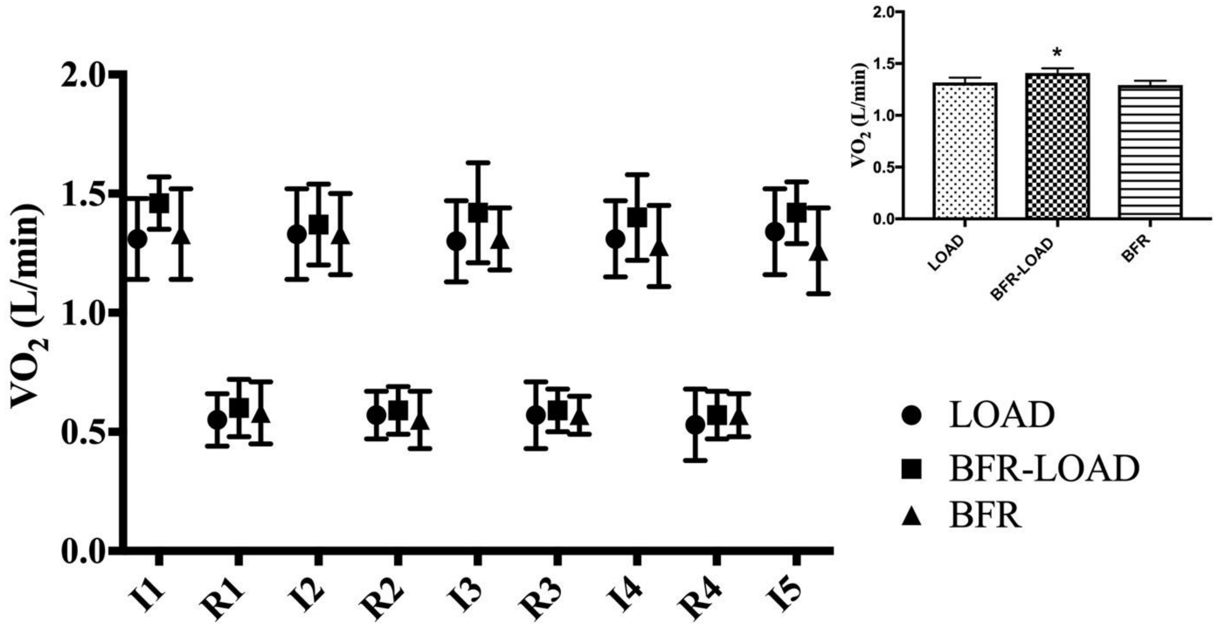

Figure 7. Oxygen uptake ($\dot{V}O_2$) during Walking Intervals and Rest
The exercise consisted of walking at 4.82 km·h^{-1} for five 3-min bouts (from Interval (I) 1 to 5) with a 1-min rest (R) between bouts between three conditions: LOAD, BFR-LOAD, and BFR. Significant differences with the BFR-LOAD condition: * $p < 0.05$.

Due to equipment malfunctions one participant's data were excluded resulting in n= 11 for SmO_2, THb, OxyHb and DeoxyHb data. There was a significant exercise condition × time effect with SmO_2, F(1, 10) = 5.294, *p* =.044, $\eta^2 = 0.346$ (Figure 8). Post hoc analysis revealed SmO_2 was significantly lower during exercise and rest with BFR-LOAD compared to LOAD, *t*(10) = -4.433, *p* < .001 and *t*(10) = -5.438, *p* < .001, respectively. Both conditions revealed a time effect with BFR-LOAD, *t*(10) = 6.083, *p* < .001 and LOAD, *t*(10) = 4.205, *p* = .002. Additionally, there was a significant exercise condition × time interaction with DeOxyHb, F(1, 10) = 5.138 *p* = .047, $\eta^2 = 0.339$. Post hoc analysis revealed DeOxyHb was significantly higher during exercise and rest with BFR-LOAD compared to LOAD, *t*(10) = 4.425, *p* < .001 and *t*(10) = 5.572, *p* < .001, respectively. Both conditions revealed a time effect with BFR-LOAD, *t*(10) = -6.522, *p* < .001 and LOAD, *t*(10) = -4.265, *p* = .002. There was no significant condition × time effect for OxyHb, F(1, 10) =3.852 p= .078 (Table 6). However, there was a significant exercise condition effect for OxyHb, F(1, 10) = 26.577, $p < .001$, $\eta^2 = .727$ and separate time effect, F(1, 10) = 24.388, $p < .001$, $\eta^2 = .709$. There was no significant condition × time effect for THb, F(1, 10) = 0.238, p= .636. But there was a significant separate time effect F(1,10) = 5.641, p = .039, $\eta^2 = 0.361$.

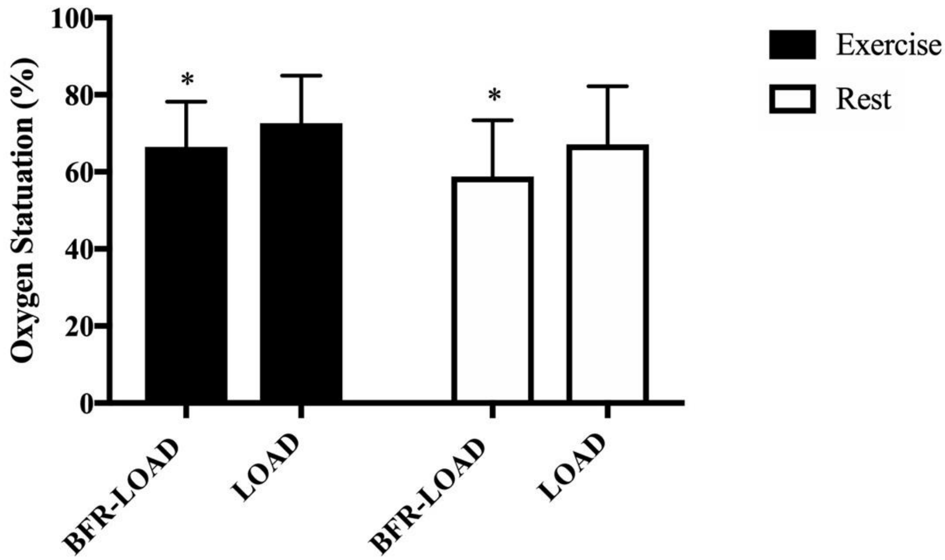

Figure 8. SmO_2 Levels (%) During Exercise and Rest with LOAD and BFR-LOAD. Significantly lower differences from the BFR-LOAD to LOAD conditions: * $p < 0.001$.

Table 6

Hemoglobin Values During Exercise and Rest for BFR-Load and Load

	BFR- LOAD Exercise	BFR- LOAD Rest	LOAD Exercise	LOAD Rest
THb ($g \cdot dL^{-1}$)	12.22 ± 0.35	12.3 ± 0.40†	12.27 ± 0.32	12.33 ± 0.32*
OxyHb ($g \cdot dL^{-1}$)	8.10 ± 1.27*	7.22 ± 1.68	8.89 ± 1.35†	8.24 ± 1.71
DeoxyHb ($g \cdot dL^{-1}$)	4.12 ± 1.52‡	5.08 ± 1.86‡	3.38 ± 1.58	4.08 ± 1.94

Mean ± SD, THb = total hemoglobin, Hb = hemoglobin. * denotes significant difference from LOAD Exercise. † denotes significant difference from BFR- LOAD exercise. ‡ denotes significant difference from LOAD Exercise and LOAD Rest (main effect of exercise type). Significant difference at $p < 0.05$.

There was no condition × time effect, F(2, 22) = 3.043, p = .068, η^2 = 0.217 nor was there a condition effect for FS between LOAD and BFR- LOAD, F(1, 11) = .589, p = .459, η^2 = 0.051. There was a significant time effect, F(2, 22) = 1.556, p = .004, η^2 = 0.389. Pairwise comparison indicated a significant difference between the baseline and the 5th interval, p = .032.

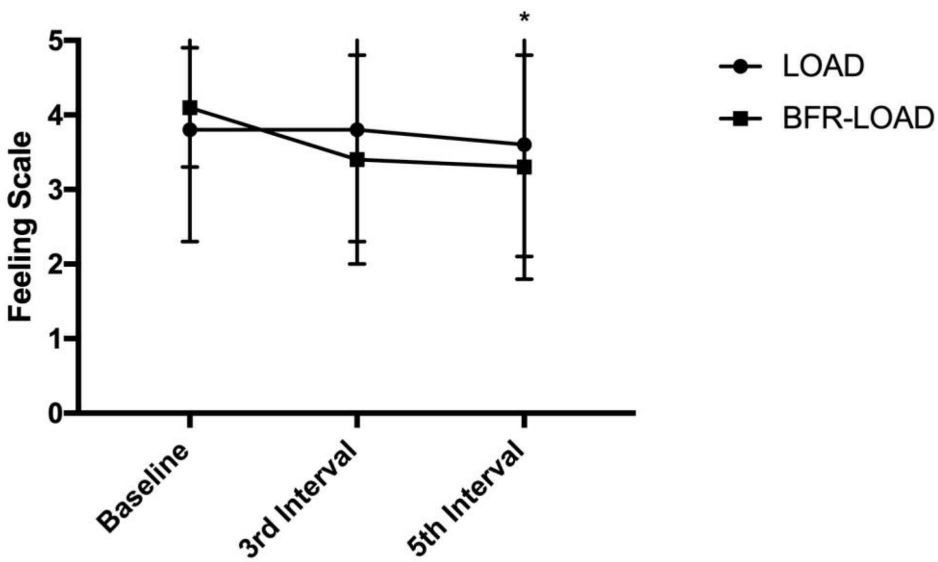

Figure 9. Feeling Scale (-5 to +5) data
During baseline and the end of the 3rd and 5th interval in both with LOAD and BFR-LOAD.
*Significant differences between Baseline and 5th Interval, $p < 0.05$.

4.5. Discussion

The purpose of this investigation was to compare the acute metabolic and perceptual responses with load carriage walking with and without BFR. The main finding of this study was that BFR-LOAD elicited increased $\dot{V}O_2$ consumption during exercise and decreased muscle O_2 saturation during both exercise and rest. There was no difference in heart rate response or feeling scale between the conditions. Interestingly, there were statistically similar effects between BFR walking and walking with only load carriage providing some further implications for training.

With the BFR-LOAD there was significantly greater $\dot{V}O_2$ consumption versus LOAD condition. This overall increase in net $\dot{V}O_2$ has been observed during walk training with BFR previously (Mendonca et al., 2014). Unexpectedly were there no differences observed between the LOAD Condition and BFR session used as a familiarization session for the participants. With similar metabolic responses, individuals that are unable or restricted from carrying load may use BFR as a mode for comparable acute metabolic effects. When increasing load carriage of an individual, the kinetic energy required will also increase, which results in the loss of efficiency and an increase in O_2 demand (Clark, West, et al., 2013; Solomonson et al., 2016). The influence of load carriage has shown a systematic increase in $\dot{V}O_2$, HR, and ventilation (Abe et al., 2008; Beekley et al., 2007; Phillips, Stickland, et al., 2016; Walker et al., 2015). When load carriage is not standardized for body mass, as it is for most military occupations, further increases in metabolic demand can be seen in smaller individuals (Beekley et al., 2007; Lyons, Allsopp, & Bilzon, 2005). These data present compelling evidence that the use of BFR could be used to elicit metabolic responses similarly observed while performing ambulatory activities (i.e., walking) with load carriage.

With BFR, venous return and stroke volume are typically reduced due to the vascular resistance from the inflation of the cuff (Renzi et al., 2010). Due to this decrease in stroke volume, HR must increase to maintain cardiac output (Renzi et al., 2010). During this study, the increase in HR was not found to be statistically significant. The researchers suspect that there are several explanations for this lack of response. First, the participants were walking at 4.8 $km \cdot h^{-1}$ which is a low intensity with this physically active sample (est. $\dot{V}O_{2max}$ 55.29 ± 4.15 $ml \cdot kg^{-1} \cdot min^{-1}$). Physically fit individuals, based on aerobic capacity, tend to have lower HR during exercise showing increased stroke volume and myocardial contractility (Jones & Carter, 2000). We presume that if the intensity of the exercise were higher (e.g., increase speed, increased grade), there would have been a greater separation in HR between the two conditions. Secondly, the pressure of the cuff (156.3 $\pm$ 4.9 mmHg) was lower than compared to other studies, which used ranges from 160-230 mmHg (de Oliveira et al., 2016; Park et al., 2010; Renzi et al., 2010; Sakamaki et al., 2011). Since this was the first-time participants had used BFR, our laboratory used 1.3 times the resting systolic blood pressure as an upper limit to the pressure resulting in an average pressure of 156 $\pm$ 5 mmHg. Presumably, with higher pressure levels, venous return would reduce stroke volume, thus, increasing HR.

Muscle O_2 saturation of the vastus lateralis of the left leg was significantly lower during both the exercise and rest during BFR-LOAD then compared with the LOAD condition (-9 % and -14%, respectively) (Figure 8). DeOxyHb was significantly higher with BFR-LOAD both during exercise and rest when compared to the LOAD condition (Table 6). These higher levels are an indication of the metabolic stress (i.e., low O_2, and intercellular pH levels, high CO_2 levels) induced in the working muscles. Additionally, the BFR-LOAD condition was producing a hypoxic muscular environment. Previous research supports that with creating a hypoxic environment the results include muscular adaptation with subsequent muscular hypertrophy (Tanimoto, Madarame, & Ishii, 2005). The use of BFR in concurrence with load carriage could produce favorable increases in muscle hypertrophy in addition to the aerobic benefits previously mentioned. However, since this was an acute study, we can only speculate on the adaptations from BFR during a load carriage exercise training program.

The perceptual responses to various exercise stimuli were assessed using the FS representing levels of pleasure or displeasure in the context of exercise. There was no significant difference between LOAD and BFR-LOAD where the measure was trending towards significance (p =.068) with a medium to large effect size ($\eta^2 = 0.217$). There was a significant time difference between intervals $p = .004$. These differences are showing FS declined over time between the baseline and the fifth interval. These results suggest that the responses to the exercise associated with a more significant decline in pleasure over time attributed to the increased metabolic cost of the exercise.

This investigation utilized a novel model of acute BFR sessions as a mode of exercise implemented in combination with load carriage as a training method for military load carriage tasks. BFR training with aerobic exercise provides some acute mechanisms that could be beneficial to load carriage: 1) increased muscle recruitment during exercise (Takada et al., 2012), 2) increased duration of metabolic acidosis with the accumulation of waste products signaling hormonal responses (Burgomaster et al., 2003), 3) metabolic adaptations from changes in oxygen delivery (Downs et al., 2014) , and 4) improvements in endurance capacity (i.e., oxidative enzymes, capillary density, stroke volume, and decreased exercising HR) (Abe et al., 2010; Park et al., 2010). This mode of aerobic exercise has shown to be beneficial with athletes (Park et al., 2010), older adults (Abe et al., 2010), even astronauts in preparation for microgravity environments (Hackney et al., 2012) as well as possibly applicable method of training for load carriage with military personnel.

Limitations of the study included the recruitment of only fit young healthy male participants as there was an additional requirement for female participants (e.g., pregnancy testing and unable to be on birth control) with the addition of BFR. The participants had higher levels of fitness, which may have impacted the cardiovascular and metabolic responses at the lower intensities. Consequently, researchers suspect there was no time effect in $\dot{V}O_2$ consumption due to the low intensity of the exercise. Even with these limitations, our study presents compelling data for future investigations using BFR and load carriage.

Our finding suggests further investigation of BFR as a method to train or recondition military personnel for walking with load carriage is warranted. Blood flow restriction exercise can also be used by military personnel who may not be able to tolerate training with high loads for various reasons but may benefit from low-load training with BFR. An example would be an individual walking with load carriage equivalent to 15% of their body mass with BFR to reproduce metabolic response similar to walking with a higher percent of load carriage. Progressive training models using BFR could prepare personnel for the rigors of load carriage. In addition, higher levels of aerobic and muscular endurance have been found to protect against common military injuries (Schuh-Renner et al., 2017). Blood flow restriction sessions as a mode of low-intensity training exercise in combination with load carriage could be implemented as rehabilitation or reconditioning training model for load carriage tasks.

4.6. Conclusion

Low-intensity walking with the addition of BFR shares metabolic characteristics similar to walking with load and may be a possible training method for military personnel while rehabilitating from injuries or reconditioning to prepare them for the rigors of load carriage in return-to-duty situations. As aerobic and muscular endurance have been found to protect against common injuries associated with load carriage. Such physical training programs not only may increase performance but longevity of these tactical professionals.

5. INCREASED PERFORMANCE MARKERS AND LOAD CARRIAGE IN ARMY ROTC CADETS USING THE CRITICAL VELOCITY MODEL

5.1. Abstract

Load carriage is an inherent part of the military and the mass required to be carried can be dependent on the range and length of the operation. Critical velocity (CV), or maximal aerobic steady state velocity, has been associated with technical and combat-specific performance measures in tactical populations. The running 3-min all-out exercise test (3MT) provides estimates of CV and the maximal capacity to displace the body (*D'*) at speeds above CV. The purpose of this study is to evaluate the effects of using the CV model to prescribe two separate high-intensity interval training (HIT) exercise programs aimed at enhancing CV and load carriage performance. **Methods:** Twenty young adult participants (male = 15, female = 5, age = 21.8 $\pm$ 1.5 yrs, height = 176 $\pm$ 8.9 cm and body mass = 78.2 $\pm$ 11.3 kg) underwent a 4-week training period where they trained 2 $d \cdot wk^{-1}$. The participants were randomly assigned to two groups: 1) HIT or 2) Load Carriage-HIT (LCHIT). Pre/post training assessments included muscle strength and endurance on the Biodex, body composition assessed by dual-energy X-ray absorption (DXA), running 3MT to determine CV and *D'*, and two load carriage tasks (400 m and 3200 m). **Results:** There were significant increases with CV (p = .005) and velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) (p = .037) among the sample but there was no statistical difference between the training groups. Load carriage completion time improvements were also observed for the 3200 m load carriage task (p < .001) with a 9.8% decrease in the LCHIT group compared to 5.4% decrease with the HIT group. Fat mass decreased significantly (p = .037) in both groups. **Conclusion:** The CV model used to prescribe exercise over four weeks of 2 $d \cdot wk^{-1}$ HIT showed improvements in CV, $v\dot{V}O_{2max}$, and load carriage performance.

5.2. Introduction

Military personnel are often faced with load carriage as part of their occupation. Load carriage takes the form of equipment, weapons, body armor, and protective gear (Dennison et al., 2012; Knapik et al., 2004; Loverro et al., 2015; Ricciardi et al., 2008). Within military populations, load carriage can range from 10 - 60 kg dependent on occupation and operations. Military operations in remote combat locations often burden service members with loads more than 60 kg (Dean & DuPont, 2003; Knapik et al., 2004; Orr et al., 2012). These loads can be dependent on the range and length of the operation with an average load of 30 kg for an average infantry combat load in Afghanistan (Dean & DuPont, 2003). The ability to perform aerobic work is significantly decreased with the addition of load carriage (Knapik et al., 2004; Ricciardi et al., 2008). These decreases are due to the regular increases in the energy cost of the increasing load carriage (Beekley et al., 2007). With the increasing demand from load carriage, the physiological impacts include increased rate of perceived exertion (RPE), elevated oxygen consumption ($\dot{V}O_2$), enhanced vertical ground reaction forces (GRF), decreased capacity, and decreased tolerance to continue aerobic work exists (Notley et al., 2015; Phillips, Stickland, et al., 2016; Puthoff et al., 2006; Ricciardi et al., 2008; Taylor et al., 2016). Loss of performance can be dependent on factors such as the body size, fat-free mass, muscular strength, physical fitness level, and the intensity of the task (Knapik et al., 2012; Notley et al., 2015; Phillips, Stickland, et al., 2016).

As a method to decrease the negative influence of load carriage, interval training using progressive overload with increasing repetitions, distances, and decreasing rest time, has been prescribed to enhance both aerobic and anaerobic energy systems (Harman et al., 2008; Hendrickson et al., 2010). Interval training is usually part of concurrent training with combined resistance and aerobic endurance training programs as well-known methods to improve load carriage performance (Knapik et al., 2012; Orr et al., 2010). Interval training for load carriage can be conducted at 80-100 % of $\dot{V}O_{2max}$ using work to rest ratios (W:R) that vary from 1:1 to 1:4 (Kraemer et al., 2004). These interval methods can evoke specific acute metabolic responses from the exercise prescription (e.g., increases in heart rate (HR), $\dot{V}O_2$, and blood lactate levels). The bouts should last three to five minutes, that is optimal for evoking the most substantial gains in aerobic fitness while enhancing performance and aerobic metabolism (Coggan et al., 1993; Hickson et al., 1977; Knuttgen et al., 1973). Previous research reports using 400, 800, 1200, and 1600 m runs conducted close to maximal intensity derived from a 3.2 km time trial with a 1:1 recovery time during an 8-week training program (Hendrickson et al., 2010). As part of concurrent training, interval training has contributed to the improvement of load carriage performance as well as occupationally specific tasks (Harman et al., 2008; Hendrickson et al., 2010; Knapik et al., 2012; Kraemer et al., 2004).

The 3-min all-out running test (3MT), provides estimates of critical velocity (CV) and running capacities at speeds exceeding CV (*D'*) (Pettitt et al., 2012). Critical velocity represents the speeds maintained for an extended period from the aerobic energy systems. Conversely, when individuals run at velocities exceeding CV, the finite capacity of *D'* regulates the time delay of the slow component in the rise toward $\dot{V}O_{2max}$ (Poole et al., 2016). The higher the *D'*, the longer distance the runner can travel at speeds exceeding CV, where running performance is found to be dependent on both CV and *D'* (Pettitt et al., 2012). The 3MT allows for testing a more significant number of participants with resources commonly available to this population (e.g., in/outdoor track, stopwatches). Critical velocity associates with technical and combat-specific performance measures in tactical populations (Dicks, Joe, Hackney, & Pettitt, 2018; Fukuda et al., 2012; Hoffman et al., 2016; Solomonson et al., 2016).

Progressive load carriage can be part of an exercise training program where the speed and distance of the march and the mass of the load carried can be manipulated to improve load carriage performances (Knapik et al., 1990). Specificity is an essential concept to improving load carriage performance, where the training is relevant and appropriate for the desired effect (Hendrickson et al., 2010; Kraemer et al., 2001; Kraemer et al., 2004; Orr et al., 2010). Improvements in load carriage are facilitated by implementation of regular load carriage activities two to four times a month within physical training programs (Knapik et al., 1990; Knapik et al., 2012). Critical velocity has shown utility for predicting and training for load carriage. Solomonson et al. (2016) found that with the addition of a 19 kg weighted vest during an all-out running test, performances were highly dependent on CV and running economy (Solomonson et al., 2016). Moreover, Solomonson et al. (2016) developed an equation for predicting sprinting times of various tactical loads based on the performance of a running 3MT. This equation was further evaluated and shown to be an accurate prediction for loaded sprinting distances of 800 m (Dicks et al., 2018).

The CV concept has been used as a method of interval exercise prescription with collegiate level soccer players and demonstrated the improvement of CV (6%) from a two $d \cdot wk^{-1}$, 4-week training program (Clark, West, et al., 2013). Prescribing HIT using the CV concept, while adjusting for a load, is a novel approach in training tactical professionals to decrease the effects of load carriage on running economy and velocity. Therefore, the primary purpose of this study was to evaluate the effects of using the CV model to prescribe two separate HIT regiments aimed at enhancing CV and load carriage performance. The secondary purpose was to assess body composition, muscle strength, and muscle endurance following these four-week HIT regiments.

5.2.1. Participants

A sample of 22 healthy young adults was recruited for participation through the host university's Army Reserve Officer's Training Corps (ROTC). Due to injuries sustained outside of this study, two of the participants were unable to complete the study. A sample of 20 ROTC cadets (male = 15; female = 5, age = 20.6 ± 1.65 yrs, height = 176 ± 8.9 cm, body mass = 78.2 ± 11.3 kg, and body mass index [BMI] = 25.2 ± 2.5 kg·m^2) completed this study. The participants were recreationally active as defined by completing both aerobic and resistance training two to five days per week for at least the past six months. Additionally, the participants were familiar or had experience with load carriage either through body armor, backpack wear or both. Participants were part of a homogeneous sample assigned to one of two groups (Table 7) with no significant differences between groups ($p < 0.05$).

Table 7

Demographic Data: High-Intensity Interval Training and Load Carriage

Demographics	LCHIT Group	HIT Group
Age (yrs)	20.6 ± 1.65	21.20 ± 1.62
Height (cm)	175.29 ± 9.17	176.61 ± 9.09
Body Mass (kg)	76.46 ± 9.48	79.88 ± 13.11
BMI (kg·m^2)	24.84 ±1.99	25.48 ± 2.92
PA-R (0-15 Scale)	8.4 ± 1.84	8.4 ± 2.27
Females (#)	2	3

Mean ± SD, LCHIT= Load carriage high-intensity interval training, HIT= high-intensity interval training, PA-R= Physical Activity-Rating

All participants were part of ROTC, taking part in physical training two d·wk^{-1}. The ROTC physical training program consisted of bodyweight circuit training, muscle endurance exercises (e.g., push-ups and sit-ups), and medium distance runs (3- 5 km). Participants were attending the ROTC physical training on Mondays and Fridays during the study. They completed their HIT sessions on Tuesday and Thursday. Road marches (6 to 9.5 km) with 13.5 to 16 kg were conducted on two occasions during the four weeks as part of the requirements from the ROTC program.

5.2.2. Documentation

Before the start of data collection, the Institutional Review Board at North Dakota State University approved this study. Participants completed the Physical Activity Readiness Questionnaire (PAR-Q), Health History Questionnaire, dual-energy X-ray absorption (DXA) screening form and provided written informed consent. Researchers reviewed completed PAR-Qs and Health History Questionnaires to determine if subjects were healthy and capable of participating in the study. Participants were excluded from the study if: 1) they did not meet the required physical activity criteria; 2) they had any previous injuries in their neck, back or legs; 3) they were taking any medications for high blood pressure/hypertension; 4) if determined they have any known or major signs of cardiovascular, pulmonary, metabolic disease or have two or more major coronary risk factors, or other reasons needing a medical clearance from the Health History Questionnaire.

5.2.3. Procedures

Two groups with counterbalanced male and female participants completed HIT intervals over four weeks following a quasi-experimental design. The groups completed pre-testing measures during week one with anthropometric measurements including body composition, running 3MT, muscle strength and endurance tests, 400 m and 3200 m load carriage tasks. The HIT group (n = 10) participated in two interval sessions per week for four weeks (eight sessions).

The Load Carriage HIT (LCHIT) group (n = 10) also completed the same HIT training (eight sessions); however, one of the weekly sessions (four in total) consisted of HIT with load carriage (15-24% of participants' body mass) (Figure 6, Ch 3). After determining the participants' CV and *D'*, each participant's specific interval velocity was calculated. Interval speed was assigned:

$$Vt = [(D' \times 0.60)/\, t_{LIM}] + CV, \tag{5.1}$$

where *Vt* is, the interval velocity and time limit (t_{LIM}) would be the interval time in seconds. Both groups started with a 180-second interval depleting 60% of *D'*. The intensity of the intervals were evolved with velocity week by week. The LCHIT groups' CV adjustment for their intervals were adjusted using the following equation (Solomonson et al., 2016):

$$\text{Adjusted CV} = \text{Original CV} + (-0.0638 \times \%\text{Load}) + 0.6982. \tag{5.2}$$

The starting point for load carriage was 15% of the participant's body mass. Participants conducted the interval workouts on a calibrated treadmill. The conversion of treadmill speed and grade was determined from the table appearing in previous literature (Pettitt et al., 2012). After the four weeks, the groups completed the same testing measures as done in week 1 with body composition, running 3MT, muscle strength and endurance tests, 400 m and 3200 m load carriage tasks. Both pre and post testing week were done without any additional physical training sessions.

5.2.4. Measures

5.2.4.1. Body Composition

Body composition was evaluated using a DXA via a GE Healthcare Lunar Prodigy, Model #8915 bone densitometer. All females took a pregnancy test before the scan to ensure the participant's safety. Each scan took five to ten minutes and had minimum radiation exposure. Researchers ensured participants were wearing appropriate clothing (athletic shorts and t-shirt) for the scan and asked participants to remove any metal or other objects that may interfere with the scan. Data included fat mass and lean mass.

5.2.4.2. Muscle Strength and Endurance

Muscle function of the upper right leg was assessed using a Biodex Pro4 System dynamometer (Biodex Medical Systems, Shirley, NY, US). The participants were seated in an upright position and moved the knee joint through flexion and extension at angular velocities of 60 and 180 degrees·second^{-1}, to examine the isokinetic strength and endurance of the knee flexors and extensors, respectively. Muscle strength testing included three maximal effort repetitions to determine peak torque (N·m) during extension. Muscle endurance test consisted of 21 maximal effort repetitions to assess total work (J). Participants were given a practice set prior to each test.

5.2.4.3. Running 3-Minute All-Out Exercise Test

Participants completed the 3MT on an indoor 200-meter running track. After 10 minutes of active warm-ups and dynamic stretches, participants were fitted with a watch (V800, Polar, Finland), telemetry heart rate monitor (H7, Polar, Finland), and a tri-axial accelerometry foot pod (Styrd, Boulder, CO, USA) sampling at 1 Hz. Participants were instructed to run an all-out maximal effort through the duration of the test. Researchers provided verbal encouragement throughout the test but did not provide elapsed time or time remaining to deter pacing. Data were downloaded from the commercial software by the watch manufacturer and exported to Microsoft Excel (v16) (Microsoft, Redmond, WA, USA) for analysis.

The running 3MT allowed researchers to estimate CV (aerobic capacity) and the running capacities at speeds exceeding CV (*D'*). Measuring CV as an average speed during the last 30 seconds of the test. Finite capacity to operate above CV (*D'*) is calculated from the average velocity during the first 150 seconds (V_{150s}) with the following equation (R.W. Pettitt et al., 2012):

$$D' = 150s\ (V_{150s} - CV). \qquad (5.3)$$

Also, the velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) was calculated as the speed value ($m \cdot s^{-1}$) 90 seconds into the test (Pettitt et al., 2012).

5.2.4.4. Interval Prescription

Critical velocity and *D'* measurements were used to prescribe intervals with and without load carriage. The groups completed HIT intervals for two days a week for four weeks (see Figure 6). Clark et al. (2013) used a four-week HIT program with a women's soccer time and yielded statistical improvements in CV. Using a prescription depleting 60% of *D'* as an example interval the equations are as follows:

$$Vt = [(D' \text{ x } 0.60)/\ t_{LIM}] + CV, \qquad (5.4)$$

where *Vt* is, the interval velocity and t_{LIM} would be the interval time in seconds.

For example, a participant's results from the 3MT yielded CV= 4.25 $m \cdot s^{-1}$ and *D'* = 112.5 meters.

$$Vt = [(112.5 \text{ x } 0.60)/180] + 4.25$$

$$Vt = 4.63\ m \cdot s^{-1}$$

The participant completed four intervals of 3 minutes running on a treadmill at 3.98 $m \cdot s^{-1}$ with 4 % grade with a 1:1 work: rest ratio (3 minutes rest). A speed limit of 3.98 $m \cdot s^{-1}$ (8.9 mph) was imposed to avoid changes to running form and to prevent any accidents on the treadmill belt.

LCHIT Intervals with 60% Depletion *D'* for 3 min (180s) =

Example participant with 15% of BM for load carriage equation b:

Adjusted CV = 4.25 + (-0.0638 x 15%) + 0.6982

Adjusted CV = 3.99 $m \cdot s^{-1}$

The participant complete four intervals of 3 minutes running on a treadmill at 3.98 $m \cdot s^{-1}$ at 0% grade with 15% of body mass for load carriage with a 1:1 work: rest ratio (3 minutes rest).

5.2.4.5. Load Carriage Tasks

Each participant completed two load carriage tasks: 1) 400 m and 2) 3200 m, both with 21 kg as the load. The participant wore an adjustable, weighted, short-waist vest to replicate load carriage (VMax Weightvest.com, Rexburg, ID, USA). The vest was fitted and adjusted for comfort before testing. Participants completed the 400 m or 2 laps around the track as fast as possible. No less than a 10-minute break was provided then completed the 3200 m or 16 laps around the indoor track as quickly as possible. During the break, participants removed the weighted vest and were encouraged to hydrate and rest.

5.2.5. Statistical Analysis

All statistical analyses were conducted using SPSS (version 24). Statistical significance used was set at the 0.05 level of confidence. Separate group (HIT vs. LCHIT) by time (pretesting vs. post-testing) factorial analysis of variance assessed the differences in CV ($m \cdot s^{-1}$), *D'* (m), the velocity at $\dot{V}O_{2max}$ ($m \cdot s^{-1}$), peak force (N·m), total work (J), time to completion for load carriage tasks (min and s), percent body fat, percent lean mass and total body mass (kg). Partial Eta Squared (η^2) was used to detect effect size of the independent variables within the model. Independent sample *t*-tests were used for comparison of demographic data between the groups. Post hoc effect size (ES) differences were calculated from pre to post measures using Cohen's d (mean difference divided by pooled SD) (Cohen, 1988). Where the scale for interpretation is as follows: less than 0.1 = trivial effect, 0.1-0.3 = small effect, 0.3-0.5 = moderate effect and greater than 0.5 = large effect.

5.3. Results

The results from the foot pod during the 3MT yielded visual results similar to those seen using waypoints or GPS (Clark, West, et al., 2013; Dicks et al., 2018; Pettitt, 2016; Pettitt & Dicks, 2017; Pettitt et al., 2012). The slope of velocity relative to time during the last 30 seconds of the 3MT was calculated, and we compared these data to the threshold values previously published (-0.004 to 0.007) to ensure participants did not pace (Dicks et al., 2018). Additionally, pre and post CV, *v*V̇O2max and *D'* values were determined (Table 8). A representative participant's results at pre-testing and post-testing appear in Figure 10. The participants were statistically evaluated (n=20) completing every workout along with pre-testing and post-testing. Exercise data from the load carriage intervals using the regression equation for speed adjustment evoked progressively higher end interval HR as well as end exercise at or near HR_{max} (Figure 11). There was no significant group × time effect, $F(1, 18) = 2.183$, $p = .157$, $\eta^2 = .108$ for CV but there was a significant time effect $F(1, 18) = 10.02$, $p = .005$, $\eta^2 = .358$ (Figure 12). Similar results were seen with $v\dot{V}O_{2max}$ with no significant group × time effect, $F(1, 18) = 0.760$, $p = .395$, $\eta^2 = .040$, but a significant time effect $F(1, 18) = 5.06$, $p = .037$, $\eta^2 = .037$. There was no significant group × time effect or time effect for *D'*, $F(1, 18) = 0.463$, $p = .505$, $\eta^2 = .025$ and $F(1, 18) = 1.72$, $p = .207$, $\eta^2 = .087$, respectively.

Table 8

3-Minute All-Out Running Test from Pre and Post-testing

Measure	Pre-Test Mean ± SD	Post-Test Mean ± SD	Cohen's D ES	Percent Δ (%)
HIT CV ($m \cdot s^{-1}$)	3.43 ± 0.56	3.60 ± 0.56∗	0.19	4.8
HIT $v\dot{V}O_{2max}$ ($m \cdot s^{-1}$)	3.96 ± 0.57	4.15 ± 0.64∗	0.21	4.8
HIT *D'* (m)	154.3 ± 36.2	149.9 ± 50.6	-0.07	-2.9
LCHIT CV ($m \cdot s^{-1}$)	3.67 ± 0.59	3.73 ± 0.48∗	0.07	1.6
LCHIT $v\dot{V}O_{2max}$ ($m \cdot s^{-1}$)	4.15 ± 0.50	4.23 ± 0.46∗	0.12	2.0
LCHIT *D'* (m)	160.3 ± 46.3	146.4 ± 23.7∗	-0.24	-8.7
Pooled CV ($m \cdot s^{-1}$)	3.55 ± 0.57	3.66 ± 0.51∗	0.21	3.2
Pooled $v\dot{V}O_{2max}$ ($m \cdot s^{-1}$)	4.05 ± 0.53	4.19 ± 0.55∗	0.17	3.4
Pooled *D'* (m)	157.3 ± 40.5	148.1 ± 38.5	-0.16	-5.8

ES= Effect size, LCHIT= Load carriage high-intensity interval training, HIT= high-intensity interval training, CV= Critical Velocity, $v\dot{V}O_{2max}$ = velocity at $\dot{V}O_{2max}$, ∗Significant differences from pre to post-testing ($p < 0.05$).

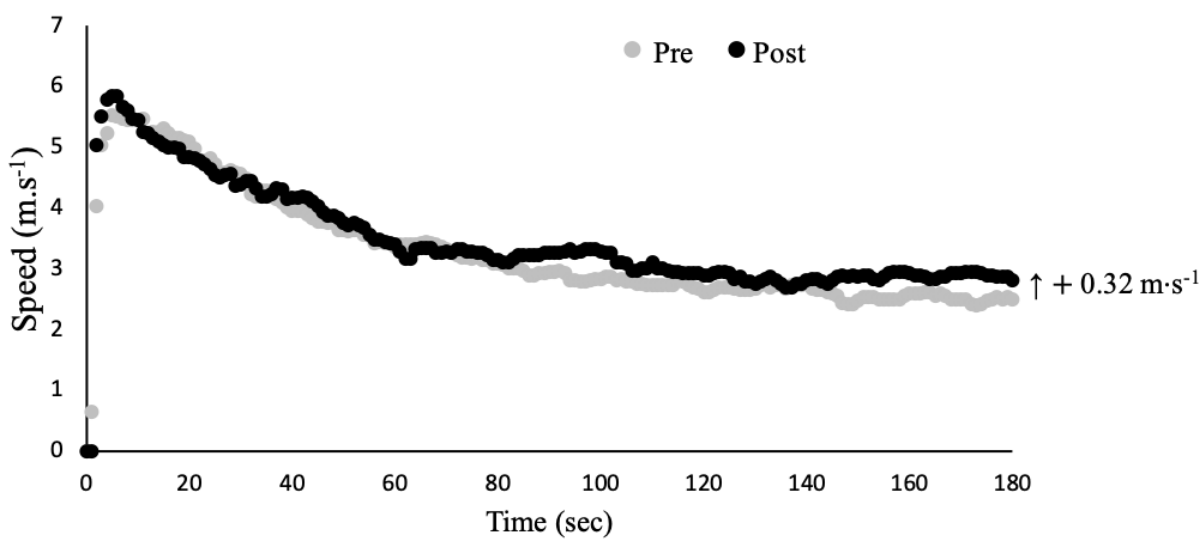

Figure 10. 3-Minute All-Out Running Test for a Representative Participant

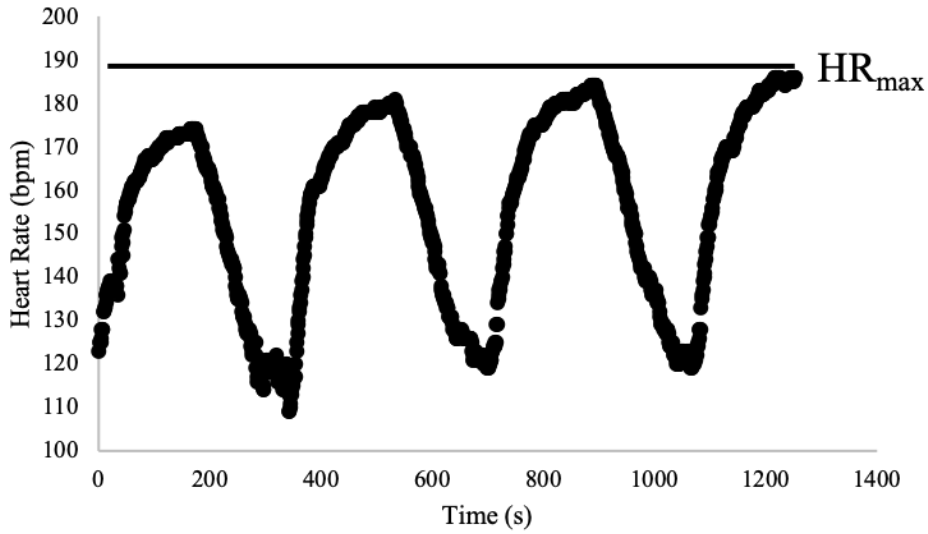

Figure 11. Heart Rate Response from a Representative Participant
Load Carriage HIT Prescription wearing 15% of Body Mass (12.3 kg) completing four × 3 minute intervals with 3 minute rests at a speed of 12.87 km·h^{-1}

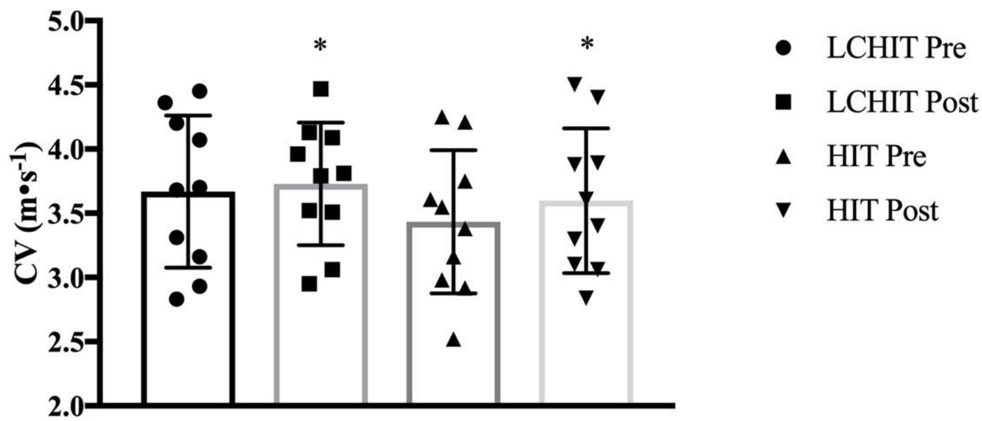

Figure 12. Critical Velocity Results from Pre and Post-testing with LCHIT and HIT Groups
* Significant differences from Pre CV ($p < 0.05$).

For load carriage variables, there was no significant group × time effect, $F(1, 18) = 0.08$, $p = .228$, $\eta^2 = .08$ for the loaded 3200 m task, but there was a significant time effect $F(1, 18) = 20.837$, $p < .001$, $\eta^2 = .537$ (Figure 13). Similar results were seen for the loaded 400m task with no significant group × time effect, $F(1, 18) = 0.20$, $p = .66$, $\eta^2 = .011$ but a significant time effect

F(1, 18) = 12.51, $p = .002$, $\eta^2 = .410$. Comparison of load carriage task completion times are displayed in Table 9.

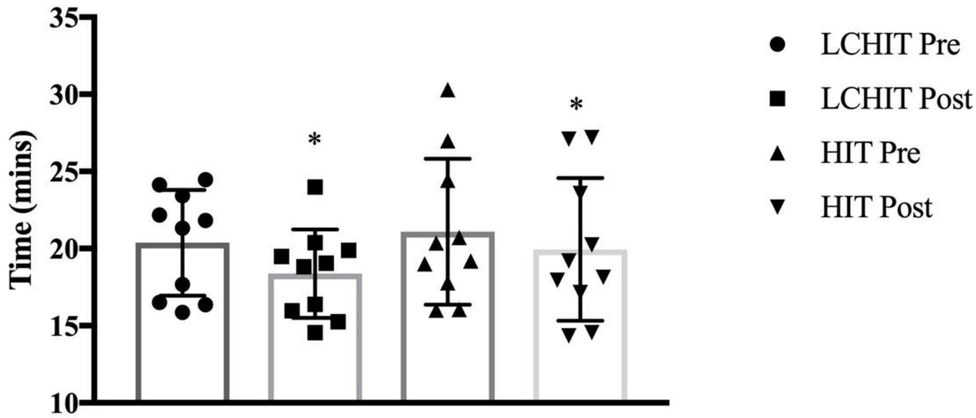

Figure 13. 3200 m Load Carriage Time to Completion
* Significant differences from Pre Times ($p < 0.001$).

Table 9

Load Carriage Task Completion

Measure	Pre-Test Mean ± SD	Post-Test Mean ± SD	Cohen's D ES	Percent Δ (%)
HIT 400 m (s)	97.4 ± 18.8	92.5 ± 18.8∗	0.26	-5.0
HIT 3200 m (min)	21.1 ± 4.73	19.94 ± 4.63*	0.24	-5.4
LCHIT 400 m (s)	89.5 ± 12.3	85.7 ± 10.7*	0.33	-4.2
LCHIT 3200 m (min)	20.38 ± 3.42	18.38 ± 2.86*	0.64	-9.8
400 m (s)	93.5 ± 16	89.1 ± 15*	0.28	-4.7
3200 m (min)	20.73 ± 4.03	19.16 ± 3.83*	0.40	-7.6

ES= Effect size, LCHIT= Load carriage high-intensity interval training, HIT= high-intensity interval training ∗Significant differences from pre to post-testing ($p < 0.05$).

With body composition variables, there was no significant group × time effect, F(1, 18) = .030, $p = .864$, $\eta^2 = .002$ for fat mass but there was a significant time effect F(1, 18) = 5.097, $p = .037$, $\eta^2 = .221$ (Figure 14). There was no significant group × time effect or time effect for total body mass, F(1, 18) = 0.86, $p = .773$, $\eta^2 =.005$ and F(1, 18) = 1.42, $p = .248$,

$\eta^2 = .073$, respectively. There were also no significant group × time effect or time effect for lean mass, $F(1, 18) = 0.95$, $p = .762$, $\eta^2 = .005$ and $F(1, 18) = .430$, $p = .520$, $\eta^2 = .023$.

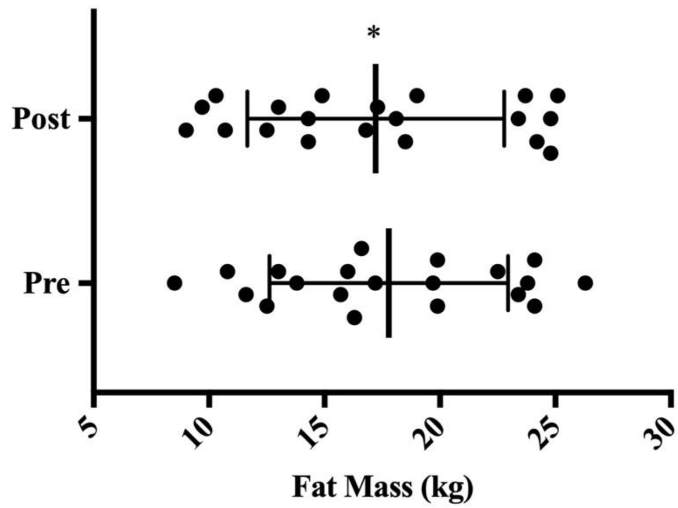

Figure 14. Pre and Post Fat Mass Measures
Data from HIT and LCHIT Pooled. * Significant differences from Pre-Fat Mass ($p < 0.05$).

Knee extensor muscle strength (peak torque) testing resulted in no significant group × time effect $F(1, 18) = 0.01$, $p = .924$, $\eta^2 = .001$ or time effect $F(1, 18) = 3.578$, $p = .075$, $\eta^2 = .166$. Knee extensor muscle endurance (total work) testing resulted in no significant group × time effect $F(1, 18) = 3.416$, $p = .081$, $\eta^2 = .159$ or time effect $F(1, 18) = 1.07$, $p = .314$ (Figure 15).

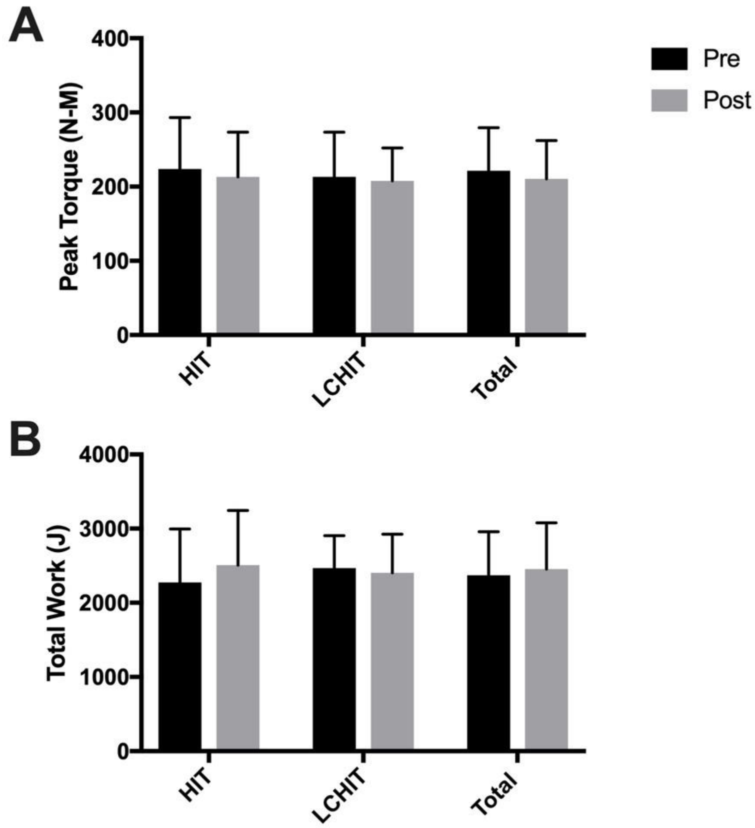

Figure 15. Knee Extensor Peak Torque and Total Work Results.
Knee Extensor Peak Torque (A) and Total Work (B)

5.4. Discussion

In this investigation we utilized the CV model to prescribe HIT and observed increased physiological performance markers, which translated into reduced military load carriage task completion times. The principal findings from this investigation were as follows. Four weeks of HIT exercise performed two days per week was appropriate to see small (.21), ES improvements in CV and $v\dot{V}O_{2max}$ in both groups. There was an 8.7% decrease in *D'* with the LCHIT group, whereas the HIT group only showed a decrease of 2.9%. Most importantly, there were moderate (.40), ES improvements observed in the load carriage task performances times for the 3200 m. Lastly, both training groups showed significant decreases in fat mass while participating in the study.

The use of the CV model has shown to produce increases in CV and $v\dot{V}O_{2max}$ in athletes (Clark, West, et al., 2013). This study was able to produce improvements in these variables with ROTC cadets (Table 8). Overall, there was a 3.2% and 3.4 % increase in CV and $v\dot{V}O_{2max}$, respectively. This increase translates to similar improvement for the two-mile run as part of the Army Physical Fitness Test, reducing times by 25-35 seconds. Unexpectedly, we saw a trivial, ES improvement in CV for the LCHIT group. As discussed earlier, four of the eight intervals for this group, the speed was adjusted based on the % of body mass they were assigned. Thus, the speed of the interval with the load was closer to their original CV value. For example, a participant had a CV of 3.15 $m \cdot s^{-1}$ for the unloaded interval (3 × 3 min 80% depletion) their speed was 3.86 $m \cdot s^{-1}$, but with 18% of their body mass for load, the reduced speed for the interval was 3.23 $m \cdot s^{-1}$. The reduction in the interval speed that was within 3% of CV may have reduced the effects that HIT had on unloaded CV and $v\dot{V}O_{2max.}$ However, the HIT group saw a small, ES improvement in CV and $v\dot{V}O_{2max.}$ Whereas the HIT group performed all eight intervals above CV and were in the severe domain of exercise. In this domain, (above CV), accelerated depletion of phosphocreatine and glycogen stores occur and a more pronounced time-dependent rise in HR and $\dot{V}O_2$ responses are observed. Prior research indicates prescribing intervals at this intensity evoked substantial gains in aerobic fitness and increase $v\dot{V}O_{2max}$ (Coggan et al., 1993; Gaesser & Wilson, 1988; Hickson et al., 1977; Knuttgen et al., 1973; Poole et al., 1988; Tabata et al., 1996).

Significant improvements in load carriage tasks indicate the benefits of HIT on load carriage performance. The lack of significant differences between the groups suggests the aerobic fitness gains may be an essential aspect of load carriage performance within these occupational load ranges. Higher aerobic capacity associates with improved load carriage performance as well as occupational task performance under load (Huang, Nagai, Lovalekar, Connaboy, & Nindl, 2018; Robinson, Roberts, Irving, & Orr, 2018; Siddall, Stevenson, Turner, & Bilzon, 2018). During the study, two road marches (between 6 to 9.5 km) with 13.5 to 16 kg were conducted during the four weeks as part of the requirements from ROTC outside of this study. Previous research has shown improvements in load carriage include progressive load carriage two to four times a month within physical training programs (Knapik et al., 1990; Knapik et al., 2012). However, the most significant improvement with load carriage were those that implemented once weekly progressive load carriage (Knapik et al., 2012; Visser et al., 2005; Williams et al., 2002). Completion times for the load carriage tasks decreased by 4.7% and 7.6% for the 400 m and 3200 m, respectively. Comparatively, the previously mentioned studies double and tripled the length of the current study. The LCHIT group exhibited large, ES improvement with the 3200 m load carriage with a 9.8% decrease from pretesting to post-testing. These findings suggest the importance of targeting specific energy systems and muscles to improve load carriage performance as part of training programs.

Body composition is essential for combat readiness and military task performance (Huang et al., 2018; Knapik et al., 2012; Williams & Rayson, 2006). Those with lower body fat and higher fat-free mass perform better in these tasks (Huang et al., 2018). For the short duration of this study, there was a 3.2% decline in fat mass (kg) among the participants. This sample averaged 20.3% body fat percentage for males and 31.2% for females compared to other training studies focused on load carriage. Unexpectedly there was no significant increase in lean muscle mass; this could be explained due to the lack of resistance training focus on strength and hypertrophy and more utilization of body weight muscular endurance exercises and circuits in the physical training program (Harman et al., 2008; Hendrickson et al., 2010; Kraemer et al., 2004).

The interval prescription using CV and *D'* resulted in the desired metabolic responses seen previously in the Clark et al. study with soccer players (Clark, West, et al., 2013). Regardless of the duration or the percentage depletion of *D'*, there was no steady state between the intervals, with each successive interval evoking an increased HR response (Figure 11). With the intervals prescribed in the severe domain and depletion of the participants' *D'*, each session ended at or near HR_{max}. Using the regression equation to adjust CV based on the percentage of load used for the interval, similar metabolic responses to those without load occurred even with reduced interval speed (Figure 11). These metabolic responses would suggest the work completed in the intervals are comparable to evoke the effect of exercising in the severe domain even if the velocity is lower than the individuals' CV.

Even though we assessed muscle strength and muscle endurance, there were no significant effects (peak torque decreased by 5% and total work completed increased by 3.5%). Since interval training can result in a higher number, size of motor units recruited and increased the frequency of activation during training resulting in increased muscle activation and rate of force development (Hendrickson et al., 2010). However, no increase could be due to the reasons as mentioned earlier with the lack of resistance training focus on strength and hypertrophy and more utilization of body weight muscular endurance exercises. The duration of the prescribed HIT may not have been sufficient enough to elicit increases in muscle strength and rate of force development. The small decrease in muscle strength assessed could also explain the small decrease in *D'*. Where contribution to *D'* can come from anaerobic energy systems (e.g., phosphocreatine, adenosine triphosphate) in muscle.

The over ground running 3MT continues to show its utility to measure both CV and *D'*. Additionally, for practitioners working with tactical professionals that have limited logistical and time requirement, the 3MT is an ideal method to evaluate and prescribe exercise as an individualized, integrated bioenergetic system training approach for each tactical professional. The use of the CV model provides a method to keep running volume down while increasing running and load carriage performance.

This study had many strengths. First, the sample population was Army ROTC Cadets with a high adherence rate completing every workout for improving run and load carriage performance. Second, the 3MT was recorded on an indoor track using footpads with 1 s sampling data improving the accuracy of the CV, $v\dot{V}O2max$ and *D'* estimates. Third, the use of the regression equation from Solomonson et al. to assign HIT with load carriage for participants (Solomonson et al., 2016). Fourth, the use of DXA for the analysis of body composition. Fifth, females make up about 17 % of the US Army according to the Office of Army Demographics (Fiscal Year 2016); our study included five females accurately representing females for the target population. Lastly, the use of the CV model to prescribe HIT training for tactical professionals aimed at improvements in run and load carriage performances.

Even with many strengths, there were some limitations of the study. First, there was a small sample size with only 20 participants (10 in each group) as the researchers wanted to keep the sample Army ROTC Cadets. Second, there was a lack of resistance training due to the availability to the ROTC department where concurrent training for load carriage would include more than body weight exercises. Third, the 4-wk duration of the training coupled with the smaller sample size decreased the statistical power, due to limited availability. Lastly, for load carriage tasks, the researchers used an indoor track; ideally, performing on an outdoor course as it better simulates the demands of load carriage.

5.5. Conclusion

This research will add to the literature on the utility of the running 3MT and the use of CV for individually customized training to enhance performance and load carriage capability. Four weeks of two $d \cdot wk^{-1}$ HIT was appropriate to see improvements in CV and $v\dot{V}O_{2max}$ in both groups. The LCHIT group was able to maintain/marginally increase CV, and $v\dot{V}O_{2max}$ values, however, there were significant decreases in the 3200 m load carriage task completion times. The use of the CV model provides a method to keep running volume down while increasing running and load carriage performances. To our knowledge, this is the first study to use the CV model aimed at load carriage improvement.

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APPENDIX A. IRB APPROVAL #HE18106

NDSU NORTH DAKOTA STATE UNIVERSITY

December 19, 2017

Dr. Kyle J. Hackney
Health, Nutrition and Exercise Sciences

IRB Approval of Protocol #HE18106, "Blood Flow Restriction as a Training Method for Load Carriage and Acute Study"
Co-investigator(s) and research team: Nathan Dicks, Sean Mahoney, Allison Barry

Approval period: 12/19/2017 to 11/16/2017 Continuing Review Report Due: 8/1/2018

Research site(s): NDSU Funding agency: n/a
Review Type: Full Board, meeting date – 11/17/2017
Risk Level: A minor increase over minimal risk
IRB approval is based on original submission, with revised: protocol, method/procedures, recruitment message, consent form and PAR-Q screening questionnaire (received 12/15/2017).

Please utilize the attached approved Informed Consent document.

Additional approval is required:
o prior to implementation of any proposed changes to the protocol (Protocol Amendment Request Form).
o for continuation of the project beyond the approval period (Continuing Review/Completion Report Form). A reminder is typically sent two months prior to the expiration date; timely submission of the report is your responsibility. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved prior to the expiration date.

A report is required for:
o any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence (Report of Unanticipated Problem or Serious Adverse Event Form).
o any significant new findings that may affect risks to participants.
o closure of the project (Continuing Review/Completion Report Form).

Research records are subject to random or directed audits at any time to verify compliance with IRB regulations and NDSU policies.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

Sincerely,

Kristy Shirley

Kristy Shirley, CIP
Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult www.ndsu.edu/irb. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

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APPENDIX B. INFORMED CONSENT #HE18106

NDSU North Dakota State University
Health, Nutrition, and Exercise Science
1301 Centennial Blvd
Fargo, ND 58108-6050
701-231-6706

Title of Research Study: Blood Flow Restriction as a Training Method for Load Carriage: an Acute Study

This study is being conducted by:
Nathan Dicks: phone: 701-388-0300 email: nathan.dicks@ndsu.edu;
Sean Mahoney: email: sean.mahoney@ndsu.edu;
Kyle Hackney: email: kyle.hackney@ndsu.edu

Why am I being asked to take part in this research study?
You are being asked to participate in this study, because we are seeking 12 males between the ages of 18 – 40 and considered to be "regularly active" and healthy, to complete walking with load carriage during two exercise sessions.

What is it about the individual that makes them of interest to the research team?

Inclusions: You have been asked to participate, because you are "regularly active" and healthy enough for exercise. For the purposes of this study, you will be considered "regularly active" if you have completed both aerobic and resistance training 2-5 days for 100 minutes per week for the past 6 months. You will be asked to complete several health-related questionnaires to help the researchers assess if you have any condition which would preclude you from participating in the study.

Exclusions: You may be excluded from the study if you have: had any previous injuries in your neck, back or legs, you are taking any medications for high blood pressure/hypertension, you have any previous history of cardiovascular disease, have sickle cell anemia/trait, have recently had surgery, have a history of blood clots, or a history of muscle breakdown due to extreme exertion.

Additional exclusions include: individuals with a calculated body mass index (weight/height^2) of 30 kg/m^2 or greater, those with abnormal blood pressure, those with prior ligamentous, bony, or other soft tissue reconstruction to the lower-extremity, a history of deep venous thrombosis (blood clots), peripheral vascular disease (narrowing or blockage in a blood vessel), diabetes, asthma, acute fracture, tumor, or infection, are an active smoker, a user of illegal drug use, have an implanted medical device, or the inability to consent (i.e. language, disability).

What is the reason for doing the study?
The main purpose of this study is to compare the metabolic and perceptual responses to load carriage while walking with and without blood flow restriction (BFR). The results from this study will have an impact on the future research and the use of a training modality that could be used as a way to mitigate injuries to prepare lower body, back and shoulder muscles for the loading without subjecting the lumbar spine (lower back) to high inertia (high resistance to motion) activities.

What will I be asked to do?
You will be asked to attend two exercise sessions performing walking on a treadmill. The order of the tasks in the second sessions will be randomized in such a way that you may walking on a treadmill with a weight vest for one condition and with a weight vest and blood flow restriction for the other. A description of each is below:

Information/Walking Session: You will first attend an informational session to become familiar with the equipment being used in the study. During this session, you will complete the Physical Activity Readiness Questionnaire (PAR-Q) and Health History Questionnaire to determine if you are healthy enough to participate in the exercise required. You will also have your weight and height measured to calculate your body mass index. Last, a test will be performed to screen for abnormally low blood pressure. Your blood pressure will be measured while sitting and two minutes after standing up. Abnormal drops in blood pressure between positions may be grounds for exclusion from the study.

We will then familiarize you and fit you with the Kaatsu leg cuffs, which are specially designed cuffs (50 mm wide) that will be placed around the upper portion of each leg (high on the thigh). The cuff contains a pneumatic bag along its inner surface that will be connected to an electronic air pressure control system to monitor the restriction pressure. Next, we will be conducting a Kaatsu (pressure) cycle with the device. The Kaatsu cycle involves eight rounds of cuff inflation for 20 seconds followed by 5 seconds of deflation. Next,The researchers will find the optimal pressure for exercise by measuring your capillary refill time, or the time in seconds taken for color to return to the skin after depressing with a finger or thumb. You will then conduct a walking session with the Kaatsu device while breathing into a 2-way valve connected to the metabolic cart and wear a heart rate monitor. You will also wear a nose plug during testing to make sure all breath measures are collected. The walking protocol will include five sets of three minutes walking at 3 mph with zero percent grade with one minute rest in which the treadmill will be stopped. Restriction of leg muscle blood flow will be maintained for the entire exercise session, including the 1-min rest periods (total of 19 min). The belt pressure will be released immediately on completion of the session. Once you completed the walking protocol, we will remove the cuffs and then familiarize you with the weight vest and the muscle oxygen sensor that will be used for next session.

Load Carriage Walking and Loaded Walking BFR: You will complete session two in a random order completing both a walking with load carriage condition as well as a walking with load carriage and BFR condition. We will take your resting blood pressure and heart rate after five minutes of sitting prior to each exercise condition. Your second visit will either consist of: 1) walking protocol with load carriage followed by a 20-min recovery, performing a Kaatsu cycle, ending with the walking protocol with load carriage and BFR or 2) Kaatsu cycle, walking protocol with load carriage and BFR followed by a 20-min recovery, ending with walking protocol with load carriage. During the 20-min recovery session, we will let you rest and drink water in between the two different conditions. The Kaatsu cycle will be the same that was conducted during the first session and will be done before you complete the BFR condition.

Load carriage will be done through your wearing a vest loaded with a mass equal to ~15% of your measured body weight. The procedures for the walking protocol will be the same as those you performed during the first session (five sets of three minutes walking at 3 mph with zero percent grade with one minute rest). During one condition you will just wear the weight vest and conduct the walking protocol while breathing into a 2-way valve connected to the metabolic cart, wearing a heart rate monitor and have a non-invasive MOXY sensor placed on the outside of your left leg. We will also assess the feeling scale (on a scale of -5 to +5) at baseline then 15 s before the end of the third and fifth interval during the walking protocol. The other condition will be exactly the same but we will add restriction of leg muscle blood flow with the Kaatsu bands that will be inflated for the entire exercise condition, including the 1-min rest periods (total of 19 min). The belt pressure will be released immediately on completion of the session.

Where is the study going to take place, and how long will it take?
This study will take place in the North Dakota State University Human Performance Lab, room 14 or 15. Each session will last between 60 and 75 minutes long, and sessions will take place at least 48 hours apart from each other. The total time commitment for the study is approximately ≤ 150 minutes.

What are the risks and discomforts?
It is not possible to identify all risks in research procedures, but the researcher(s) have taken reasonable actions to reduce any known risks. Some of the most common risks and discomforts include: muscle soreness/cramping following exercise, lightheadedness, difficulty breathing, and increased heart rate and blood pressure. If new findings develop during this research which may change your willingness to participate, we will tell you about these findings. Due to the small risk of blood clotting during exercise and the use of BFR, you will leave the final session with a handout of possible symptoms, and researchers will contact you by phone within 24 hours of your last exercise session to monitor for signs and symptoms you may have developed after the testing sessions.

What are the benefits to me? Since this is an acute research study, you are not expected to get any benefit from participating in this research study.

What are the benefits to other people? Possible benefits to others will include new training methods that could be used with tactical professionals for load carriage, building understanding of the metabolic costs of BFR with load carriage. This finding will be fundamentally important given the future aim of developing BFR training protocols to train tactical athletes who work under load as part of their assigned duties or as a method of training during rehabilitation after injury.

Do I have to take part in the study? Your participation in this research is your choice. If you decide to participate in the study, you may change your mind and stop participating at any time.

What are the alternatives to being in this research study?
Instead of being in this research study, you can choose not to participate.

Who will see the information that I give?
We will keep private all research records that identify you. Your information will be combined with information from other people taking part in the study. When we write about the study, we will write about the combined information that we have gathered. We may publish the results of the study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two sets of information will be stored in different places under lock and key. If you withdraw before the research is over, your information will be retained in the research record OR removed at your request, and we will not collect additional information about you.

Can my taking part in the study end early?
Your participation in the study may end whenever you wish. If you choose to end your participation early, you will receive any money that you have gained up to that point (see below). If you fail to attend any of the designated session, researcher(s) may remove you from the study and you will receive any money that you have gained up to that point.

Will I receive any compensation for taking part in this study?
You will receive $20.00 after completing session 1 and $30.00 for completing the session 2, for a total of $50.00 possible compensation if you complete all the sessions. If you drop out of the study before completing both sessions you will only earn money for the session that you completed.

What happens if I am injured because of this research?
If you receive an injury when taking part in the research, you should contact Kyle Hackney (701-231-6706). If injury occurs during testing, treatment for the injury will be available including first aid, emergency treatment and follow-up care as needed. Payment for this treatment must be provided by you and your third-party payer (such as health insurance). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of your participation in this research.

What if I have questions?
Before you decide whether to accept this invitation to take part in the research study, please ask any questions that might come to mind now. Later, if you have any questions about the study, you can contact the researcher, Nathan Dicks at 701-388-0300 or nathan.dicks@ndus.edu or my advisor, Dr. Kyle Hackney at 701-231-6706 or kyle.hackney@ndsu.edu.

What are my rights as a research participant? You have rights as a participant in research. If you have questions about your rights, or complaints about this research, you may talk to the researcher or contact the NDSU Human Research Protection Program by:

- Telephone: 701.231.8995 or toll-free 1-855-800-6717
- Email: ndsu.irb@ndsu.edu
- Mail: NDSU HRPP Office, NDSU Dept. 4000, PO Box 6050, Fargo, ND 58108-6050.

The role of the Human Research Protection Program is to see that your rights are protected in this research; more information about your rights can be found at: www.ndsu.edu/irb .

Documentation of Informed Consent:
You are freely making a decision whether to be in this research study. Signing this form means that

1. you have read and understood this consent form
2. you have had your questions answered, and
3. you have decided to be in the study.

You will be given a copy of this consent form to keep.

______________________________________ ________________
Your signature Date

____
Your printed name

______________________________________ ________________
Signature of researcher explaining study Date

____
Printed name of researcher explaining study

APPENDIX C. HEALTH HISTORY QUESTIONNAIRE

Health History Questionnaire

Please answer the following questions to the best of your ability. For the following questions, unless otherwise indicated, circle the single best choice for each question. As is customary, all of your responses are completely confidential and may only be used in group summaries and/or reports. All information collected is subject to the Privacy Act of 1974. If you have any physical handicaps or limitations that would require special assistance with this questionnaire, please let your trainer know. This form is in accordance with the American College of Sports Medicine guidelines for risk stratification when followed correctly by your trainer. Your trainer should be certified with a national organization in order to use these forms correctly.

Name: ______________________ Ht.: ________ Wt.: ________

Gender: ________ Age: ________ Birthdate: ______________________

Address: ______________________

City: ______________ State: ________ ZIP: ________ Phone: ______________

Emergency Contact: ______________________ Phone: ______________

Personal Physician: ______________________ Phone: ______________

E-mail: ______________________

1. Have you ever had a definite or suspected heart attack or stroke? .... Yes No
2. Have you ever had coronary bypass surgery or any other type of heart surgery? .... Yes No
3. Do you have any other cardiovascular or pulmonary (lung) disease (***other than*** asthma, allergies, or mitral valve prolapse)? .... Yes No
4. Do you have a history of: diabetes, thyroid, kidney, liver disease. .... Yes No **(circle all that apply)**
5. Have you ever been told by a health professional that you have had an abnormal resting or exercise (treadmill) electrocardiogram (EKG)? .... Yes No
6. If you answered YES to any of Questions 1 through 5, please describe:

____

____

____

____

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P04-020

7. Do you currently have any of the following:

a. pain or discomfort in the chest or surrounding areas that occurs when you engage in physical activity? .... Yes No

b. shortness of breath .... Yes No

c. unexplained dizziness or fainting .... Yes No

d. difficulty breathing at night except in upright position .... Yes No

e. swelling of the ankles (recurrent and unrelated to injury) .... Yes No

f. heart palpitations (irregularity or racing of the heart on more than one occasion) .... Yes No

g. pain in the legs that causes you to stop walking (claudication) .... Yes No

h. known heart murmur .... Yes No

Have you discussed any of the above with your personal physician? .... Yes No

8. Are you pregnant or is it likely that you could be pregnant at this time? .... Yes No

If yes, what is your expected due date?____________________

9. Have you had surgery or been diagnosed with any disease in the past 3 months? .... Yes No

If yes, please list date____________ and surgery/disease____________________

10. Have you had high blood cholesterol or abnormal lipids within the past 12 months or are you taking medication to control your lipids? .... Yes No

11. Do you currently smoke cigarettes or have quit within the past 6 months? .... Yes No

12. Have your father or brother(s) had heart disease prior to age 55 OR mother or sister(s) had heart disease prior to age 65? .... Yes No

13. Within the past 12 months, has a health professional told you that you have high blood pressure (systolic $\geq$ 140 OR diastolic $\geq$ 90)? .... Yes No

14. Currently, do you have high blood pressure or within the past 12 months, have you taken any medicines to control your blood pressure? .... Yes No

15. Have you ever been told by a health professional that you have a fasting blood glucose greater than or equal to 110 mg/dl? .... Yes No

16. Describe your regular physical activity or exercise program:

type:____

frequency: ________ days per week

duration: ________ minutes

intensity: *low* *moderate* *high* (circle one)

BMI: _______

17. If you have answered YES to any of questions 7-16, please describe:

____

____

____

18. Are you currently under any treatment for any blood clots? .... Yes No

19. Do you have problems with bones, joints, or muscles that may be aggravated with exercise? .... Yes No

20. Do you have any back/neck problems? .... Yes No

21. Have you been told by a health professional that you should not exercise? .... Yes No

22. Are you currently being treated for any other medical condition by a physician? .... Yes No

23. Are there any other conditions (mitral valve prolapse, epilepsy, history of rheumatic fever, asthma, cancer, anemia, hepatitis, etc.) that may ***hinder*** your ability to exercise? .... Yes No

24. During the past six months, have you experienced any ***unexplained*** weight loss or gain (greater than ten pounds for no known reason)? .... Yes No

25. If you have answered YES to any of questions 18-24, please describe:

____

____

____

26. Please list below all prescription and over-the-counter medications you are currently taking:

Medicine:	Reason for taking:	Dosage:	Amount/Frequency:

27. Are there any medicines that your physician has prescribed to you in the past 12 months which you are currently not taking? .... Yes No
If so, please list:

____

____

____

I have answered the Health History Questionnaire questions accurately and completely. I understand that my medical history is a very important factor in the development of my fitness/wellness program. I understand that certain medical or physical conditions which are known to me, but that I do not disclose to my trainer, may result in serious injury to me. If any of the above conditions change, I will immediately inform my trainer of those changes. I, knowingly and willingly, assume all risks of injury resulting from my failure to disclose accurate, complete, and updated information in accordance with the attached questionnaire. I also understand that in order to properly risk stratify my Health History Questionnaire, my trainer should have a minimum of a national certification as a personal trainer. My trainer also verbally explained this statement to me to my understanding.

Client's Signature: ____________________ Date: ________

Trainer's Signature: ____________________ Date: ________

For Use by the Personal Trainer ONLY

Check the identified ACSM major coronary risk factors below:

________ Lipids (TCH ≥ 200 OR HDL < 35)	________ Cigarette Smoking (or quit within the past 6 months)
________ Family History	________ High Blood Pressure/Blood Pressure Medications
________ Diabetes/glucose ≥ 110 mg/dl	________ Sedentary
________ BMI ≥ 30	________ Pregnancy
________ Metabolic Disease	________ Respiratory Disease (asthma, emphysema, chronic bronchitis)

________ Signs or Symptoms of Cardiovascular Disease ________________________________

________ Cardiovascular Disease ________________________________

<u>Risk Stratification</u>	<u>Factors</u>
________ Apparently Healthy	One or No Risk Factors (No medical clearance required)
________ Apparently Healthy Male ≥ 45; Female ≥ 55	One or No Risk Factors (initial medical clearance required)
________ High Risk, No Signs or Symptoms	Two or More Risk Factors (medical clearance required)
________ High Risk, with Signs and Symptoms	One or More Signs/Symptoms With or Without Risks (medical clearance required)
________ Known Disease	Diagnosed Cardiopulmonary/Metabolic Disease (annual medical clearance required)
________ Pregnancy	Medical Clearance Required

All clients needing written medical clearance from their personal physician must give it to their trainer prior to beginning their exercise program.

Additional Comments: ________________________________

____

Health History Questionnaire follows the American College of Sports Medicine recommendations for risk stratification. This must be performed on all clients in order to determine the need for medical clearance and/or exercise modifications. Any trainer or those making exercise recommendations should be certified in the proper use of the risk stratification process through a national organization.

If a client has a YES response to anything on page 1, he/she has KNOWN DISEASE, and must have medical clearance prior to beginning exercise.

If he/she has a YES response to anything on #7 a-h on page 2, your client is HIGH RISK WITH SIGNS/SYMPTOMS and must have medical clearance prior to exercise. If your client has a YES response to questions # 8 or 9, he/she must have medical clearance.

YES responses to two or more on questions 10-16 on page 2, your client is HIGH RISK WITHOUT SIGNS OR SYMPTOMS and must have medical clearance (unless he/she also has a YES answer in question #7 making them still HIGH RISK WITH SIGNS/SYMPTOMS).

All other questions on page 3 are at your own discretion. Remember, **when in doubt, refer out.** Please also refer to the most recent edition of *ACSM's Guidelines for Exercise Testing and Prescription* (Williams & Wilkins) as well as the most recent edition of the *ACE Personal Trainer Manual* (American Council on Exercise) for more explanations on the risk stratification. It is your responsibility as a trainer to remain updated on all changes or modifications for risk stratification in determining the need for medical clearance and exercise modifications/recommendations.

Premier Performance, Inc.
1457 Cambridge Common
Decatur, Georgia 30033
404-406-2873
pperform@bellsouth.net

American Council on Exercise
4851 Paramount Dr.
San Diego CA 92123
800-825-3636
www.ACEfitness.org

APPENDIX D. THE PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

2017 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it *does not limit your current ability* to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

OSHF

2017 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1. Do you have Arthritis, Osteoporosis, or Back Problems?

If the above condition(s) is/are present, answer questions 1a-1c — If **NO** ☐ go to question 2

1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	YES ☐ NO ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	YES ☐ NO ☐

2. Do you currently have Cancer of any kind?

If the above condition(s) is/are present, answer questions 2a-2b — If **NO** ☐ go to question 3

2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	YES ☐ NO ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	YES ☐ NO ☐

3. Do you have a Heart or Cardiovascular Condition? *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm*

If the above condition(s) is/are present, answer questions 3a-3d — If **NO** ☐ go to question 4

3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	YES ☐ NO ☐
3c.	Do you have chronic heart failure?	YES ☐ NO ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	YES ☐ NO ☐

4. Do you have High Blood Pressure?

If the above condition(s) is/are present, answer questions 4a-4b — If **NO** ☐ go to question 5

4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	YES ☐ NO ☐

5. Do you have any Metabolic Conditions? *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes*

If the above condition(s) is/are present, answer questions 5a-5e — If **NO** ☐ go to question 6

5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	YES ☐ NO ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	YES ☐ NO ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	YES ☐ NO ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	YES ☐ NO ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	YES ☐ NO ☐

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2017 PAR-Q+

6.	**Do you have any Mental Health Problems or Learning Difficulties?** *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome* If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7	
6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐
7.	**Do you have a Respiratory Disease?** *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure* If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8	
7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐
8.	**Do you have a Spinal Cord Injury?** *This includes Tetraplegia and Paraplegia* If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9	
8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐
9.	**Have you had a Stroke?** *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event* If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10	
9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐
10.	**Do you have any other medical condition not listed above or do you have two or more medical conditions?** If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations	
10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______________________

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

01-01-2017

2017 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

NAME ______________________________ DATE ______________________________

SIGNATURE ______________________________ WITNESS ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

Key References

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APPENDIX E. DEEP VEIN THROMBOSIS (DVT) RISK ASSESSMENT TOOL

Are you or a loved one at risk for DVT blood clots?

Complete our Risk Assessment Tool to find out.

COALITION TO PREVENT DEEP-VEIN THROMBOSIS

NAME ______________________ TODAY'S DATE ____________

Only a healthcare professional can decide whether you're at risk for Deep Vein Thrombosis (DVT), or blood clots that can form in the deep veins of your legs. But, there are certain things that can put you at a higher risk for them. Take a moment to complete this form for yourself (or complete it for someone you love). Then, be sure to talk with a healthcare professional about your risk for DVT and what you can do to help prevent it. A healthcare professional may even want to keep a copy of your completed survey for future reference.

HOW TO COMPLETE THIS RISK ASSESSMENT TOOL:

1. **Check all the statements that apply to you.**
2. **Enter the number of points shown for each of your checked statements in the space at right.**
3. **Add up all your points to reach your total DVT Risk Score. Then, share your completed form with a healthcare professional.**

Add 5 points for each of the following statements that apply:

- ❑ Recent hip or knee joint replacement surgery ____
- ❑ Broken hip, pelvis, or leg within the last month ____
- ❑ Stroke within the last month ____
- ❑ Serious trauma within the last month (for example, a fall, broken bone, or car accident) ____
- ❑ Spinal cord injury resulting in paralysis within the last month ____

Add 3 points for each of the following statements that apply:

- ❑ Age 75 or over ____
- ❑ History of blood clots, either Deep Vein Thrombosis (DVT) or Pulmonary Embolism (PE) ____
- ❑ Family history of blood clots (thrombosis) ____
- ❑ Family history of blood-clotting disorders ____

Add 2 points for each of the following statements that apply:

- ❑ Age 60–74 years ____
- ❑ Recent arthroscopic knee surgery (surgery performed through a small incision with a lighted, tube-shaped instrument) ____
- ❑ Cancer (current or previous) ____
- ❑ Recently had major surgery that lasted longer than 45 minutes ____
- ❑ Recent laparoscopic surgery that lasted longer than 45 minutes (surgery performed through a small incision with a lighted, tube-shaped instrument) ____
- ❑ Recently confined to bed rest for more than 72 hours ____
- ❑ Plaster cast that has kept you from moving your limb within the last month ____
- ❑ Tube in blood vessel in neck or chest that delivers blood or medicine directly to heart (also called central venous access) ____

For women only: Add 1 point for each of the following statements that apply:

- ❑ Use of birth control or Hormone Replacement Therapy (HRT) ____
- ❑ Pregnant or had a baby within the last month ____

Add 1 point for each of the following statements that apply:

- ❑ Age 41–60 years ____
- ❑ Planning minor surgery in the near future ____
- ❑ Had major surgery within the last month ____
- ❑ Varicose veins ____
- ❑ A history of Inflammatory Bowel Disease (IBD) (for example, Crohn's disease or ulcerative colitis) ____
- ❑ Legs are currently swollen ____
- ❑ Overweight or obese ____
- ❑ Heart attack within the last month ____
- ❑ Congestive heart failure within the last month ____
- ❑ Serious infection within the last month (for example, pneumonia) ____
- ❑ Lung disease within the last month (for example, emphysema or COPD) ____
- ❑ Currently on bed rest or restricted mobility ____

Add up all your points to get your total DVT Risk Score ____

What does your DVT Risk Score mean?

Only a healthcare professional can determine your risk.

Low Risk 0-1	**What you should do about it:** Although you may not be at risk right now, it's a good idea to reassess your risk for DVT at regularly scheduled heathcare visits or annual exams.
Moderate Risk 2	**What you should do about it:** Share your answers to this survey with a healthcare professional at your next scheduled appointment so that he or she may address your risk.
High Risk 3+	**What you should do about it:** Your increased risk requires you to share your answers with a healthcare professional so that he or she may address your risk.

Talk to a healthcare professional about DVT today. It's the first step toward preventing it.

Adapted with permission from Caprini JA, Arcelus JI, et al. State-of-the-art venous thromboembolism prophylaxis. Scope. 2001; 8: 228-240.

APPENDIX F. IRB APPROVAL #HE18245

NDSU NORTH DAKOTA STATE UNIVERSITY

May 18, 2018

Kyle Hackney
Department of Health, Nutrition & Exercise Science

IRB Approval of Protocol #HE18245, "Applying the Critical Velocity Model to Increase Performance Markers and Load Carriage Capability"
Co-investigator(s) and research team: Nathan Dicks, Sean Mahoney

Approval expires: 5/10/2019 Continuing Review Report Due: 4/1/2019

Research site(s): NDSU Funding agency: Northland American College of Sports Medicine (FAR0029250)
Review Type: Full Board, meeting date – 5/11/2018
Risk Level: A minor increase over minimal risk
IRB approval is based on original submission, with revised: protocol, recruitment flyer and informed consent (received 5/18/2018). Please utilize the stamped informed consent provided.

Additional approval is required:
o prior to implementation of any proposed changes to the protocol (Protocol Amendment Request Form).
o for continuation of the project beyond the approval period (Continuing Review/Completion Report Form). A reminder is typically sent two months prior to the expiration date; timely submission of the report is your responsibility. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved prior to the expiration date.

A report is required for:
o any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence (Report of Unanticipated Problem or Serious Adverse Event Form).
o any significant new findings that may affect risks to participants.
o closure of the project (Continuing Review/Completion Report Form).

Research records are subject to random or directed audits at any time to verify compliance with IRB regulations and NDSU policies.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

Sincerely,

Kristy Shirley, CIP
Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult www.ndsu.edu/irb. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

INSTITUTIONAL REVIEW BOARD
NDSU Dept 4000 | PO Box 6050 | Fargo ND 58108-6050 | 701.231.8995 | Fax 701.231.8098 | ndsu.edu/irb

Shipping address: Research 1, 1735 NDSU Research Park Drive, Fargo ND 58102

APPENDIX G. INFORMED CONSENT #HE18245

NDSU NORTH DAKOTA STATE UNIVERSITY

Health, Nutrition, and Exercise Sciences
Dept 2620, PO Box 2620
Fargo, ND 58108-6050
701.231.6706

Applying the Critical Velocity Model to Increase Performance Markers and Load Carriage Capability

This study is being conducted by Nathan Dicks: phone: 701-388-0300 email: nathan.dicks@ndsu.edu; Sean Mahoney: email: sean.mahoney@ndsu.edu; Dr. Kyle Hackney: email: kyle.hackney@ndsu.edu

Key information about this study:

This consent form is designed to inform you about the study you are being asked to participate in. Here you will find a brief summary of the study; however, you can find more detailed information later on in the form.

- 6-week High-Intensity Interval Training study (14 total visits) each visit about 30-45 minutes
- Looking for 20 healthy adults, age(s) 18-39 years
- You must be recreationally – participating in both aerobic and resistance training two to five days per week for at least the past six months
    - Additionally, you should be familiar or have experience with load carriage either through duty gear, body armor or backpack wear
- You will be excluded from the study if:
    - you do not meet the required physical activity criteria;
    - you have had any previous injuries in their neck, back or legs;
    - you take any medications for high blood pressure/hypertension;
    - if you have any known or major signs of cardiovascular, pulmonary, metabolic disease or have two or more major coronary risk factors
    - Are pregnant or think you may be pregnant.
- $55.00 compensation available for successful completion of study

Why am I being asked to take part in this study?

The purpose of this study is to evaluate the effects of two separate high-intensity interval training (HIIT) regiments aimed at enhancing run performance and load carriage capability. The results from this study could have an impact on the future training methods with occupations where load carriage is required.

What will I be asked to do?

I. Pre-testing measures (Week 1) Three separate visits (Monday, Wednesday, and Friday):
    a. Screening Paperwork (Visit 1): You will be asked to complete forms to determine your overall health including three health history questionnaires.

Institutional Review Board
North Dakota State University
PROTOCOL #: HE18245
APPROVED: 5/18/2018
EXPIRES: 5/10/2019

b. Height and weight (Visit 1): You will be asked to stand on a digital scale, stand next to a wall with a tape measure device.

c. Muscle Testing (Visit 1): You will perform a test to determine your leg strength and endurance. You will be asked to do a warm-up on a bike and then sit in a specialized chair and asked to extend and curl your leg as hard as possible.

d. Body Composition (Visit 1): Dual-energy x-ray absorption (DXA) is considered a gold standard for assessing bone mineral density (BMD), muscle mass, and fat mass. *Females: Will be asked to provide a urine sample for pregnancy screening prior to the DXA procedure.* We ask that you dress in shorts and a T-shirt. For this procedure, two velcro straps will be placed on your lower limbs to help keep the lower body in the correct position during the scan. Once positioning is complete, the trained researchers will guide you through the procedure. You will be asked to remain still as the scanning arm moves from the top of your head to the feet and back to the head. The scan takes approximately 5-12 minutes depending on height and weight. When the scan is complete, the velcro straps will be removed, and we will assist you off the DXA table.

e. Running 3-minute all-out Test (Visit 2): We will then meet at Shelly Ellig Indoor Track to perform the running test session which will be the 3-minute all-out exercise test (3 MT). You will be taken through a warm-up then perform the test. This test involves running at full effort for 3 minutes around the track. At the completion of the test, time to cool down and stretch will be given.

f. Load carriage tasks (Visit 3): In the load carriage task, you will run 400-meters (2 laps) and 3.2km (16 laps) around the indoor track. After a warm up, you will be fitted with a weight vest (21kg or 46.2 pounds) and adjusted for comfort. You will perform a 400-meter run as fast as possible. You will be able to take the vest off while taking a 10-minute break and then will complete a 3.2km run as quickly as possible with the same weight vest. At the completion of the test, time to cool down and stretch will be given.

II. Training Weeks 2-5 (Visits 4-11)

a. After random assignment, you will be asked to take part in one of two different HIIT programs over the course of the four weeks. You will be asked to come into the Human Performance Lab on Tuesdays and Thursdays for an interval training session that will take approximately 30-40 minutes including warm up and cool down. Your intervals will be based on your performance during the running test from week 1. The interval sessions will be in a controlled environment on the treadmills where researchers will give you speed, incline, and duration of the intervals. You will have procedures and have practiced straddling the treadmill belt upon completion or volitional fatigue.

i. If assigned to the HIIT group, you will perform these sessions in your regular work out attire (i.e., shorts, t-shirt, running shoes).

ii. If assigned to the Load Carriage HIIT group, you will perform the same sessions as the HIIT group with one session a week (Thursdays) with the additional 15-

25% of your body weight through a vest weight. Your speed for the load carriage intervals will be adjusted based on the amount of weight you are carrying.

b. The interval sessions will increase in intensity over the 4-weeks (8 Sessions). With the first week's sessions being baseline for speed for both groups and baseline load for the Load Carriage groups (15% of body weight).

III. Post-testing measures (Week 6) Three separate visits (Monday, Wednesday, and Friday):

a. Muscle Testing (Visit 1): The muscle testing will be completed following the same procedures used during the pre-test.

b. Body Composition (Visit 1): The DXA scan will be completed following the same procedures used during the pre-test.

c. Running 3-minute all-out Test (Visit 2): The running test session will be completed following the same procedures used during the pre-test.

d. Load carriage tasks (Visit 3): The load carriage tasks will be completed following the same procedures used during the pre-test.

Where is the study going to take place, and how long will it take?

This study will take place between the Human Performance Laboratory (HPL) at North Dakota State University, 1301 Centennial Blvd., Fargo, ND 58102 and at the Shelly Ellig Indoor Track, 1625 14th Street North, Fargo, ND 58102. There will be a total of 14 visits (10 visits to the HPL and 4 to the indoor track) with each visit lasting 30-45 minutes. The entire study will encompass 9 to 10 hours of efforts.

What are the risks and discomforts?

As with any cardiovascular exercise, there is a potential for a heart attack. Other potential risks from doing this study include musculoskeletal injury, shortness of breath, fatigue, lightheadedness, and joint injuries. To minimize these risks, we will use published guidelines for exhaustive exercise testing. Testing will be discontinued if you exhibit any signs or symptoms indicative of underlying medical conditions. There is some risk involved in exercise testing. That risk may be higher if you fail to answer our health history questionnaire honestly. So please, it is crucial you are truthful when completing the health history questionnaire. You may experience mild discomfort at the end of exercising due to muscle "burning" and rapid breathing. Both of these events are temporary and subside with a "cool down" exercise period.

Low dose radiation exposure. The full body DXA scan is not capable of producing high doses of radiation. For example, if you had 416 full body DXA scans in one year you would still only be exposed to ~25% of the limit for radiation exposures are in the United States from natural sources that are in the environment. However, it is still considered a good practice to test for pregnancy for all females of childbearing age, before a scan is completed. Therefore, all female participants will be asked to provide a urine sample/pregnancy screen test upon arrival for testing. Any positive pregnancy test would deem any further testing halted.

It is not possible to identify all potential risks in research; however, reasonable safeguards have been taken to minimize known risks. If new findings developed during the course of the research which may change your willingness to participate, we will tell you about these findings

What are the expected benefits of this research?

Individual Benefits: You will be part of a training study aimed at increasing your cardiovascular fitness that could translate to increased running speeds and improve health. Additionally, you will get a summary of your data that would include running measures, strength, and body and bone composition.

Societal Benefits: This study would be novel in using the critical velocity model to prescribe HIIT to improve running performance. With this increase, we believe this will aid in decreasing the effects that load carriage has on running economy and velocity, thus improving performance in occupations where load carriage is an inherent part of the job. This study would be of considerable use for those professionals.

Do I have to take part in this study?

Your participation in this research is your choice. If you decide to participate in the study, you may change your mind and stop participating at any time without penalty or loss of benefits to which you are already entitled.

What are the alternatives to being in this study?

Instead of being in this research, you may choose not to participate.

Who will have access to my information?

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two sets of information will be stored in different places under lock and key. If you withdraw before the research is over, your information will be retained in the research record OR removed at your request, and we will not collect additional information about you.

How will my information be used?

We will keep private all research records that identify you. Your information will be combined with information from other people taking part in the study. When we write about the study, we will write about the combined information that we have gathered. We may publish the results of the study; however, we will keep your name and other identifying information private. Collected data may be given to another investigator for future research without additional consent.

Can my participation in the study end early?

Your participation in the study may end whenever you wish. If you fail to attend any of the designated sessions, researcher(s) may remove you from the study

Will I receive any compensation for participating in the study?

After completing week 1 Pre-testing, you will be compensated $5.00; $40.00 for completing the training weeks 2-5, pro-rated to $5.00 per session (8 sessions) and $10.00 for completing the Week 6 Post-Testing- total of $55.00 possible compensation for this study.

What happens if I am injured because of the study? [Include if applicable]

If you are injured during the course of this study, you should contact the Dr. Kyle Hackney at 701.231.6706. Treatment for the injury will be available including first aid, emergency treatment, and follow-up care as needed. Payment for this treatment must be provided by you and your third-party payer (such as health insurance or Medicaid). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a results of your participation in this research.

What if I have questions?

Before you decide whether you'd like to participate in this study, please ask any questions that come to mind now. Later, if you have questions about the study, you can contact Nathan Dicks at 701.388.0300 or nathan.dicks@ndus.edu, or Dr. Kyle Hackney at 701.231.6706 or kyle.hackney@ndsu.edu.

What are my rights as a research participant?

You have rights as a research participant. All research with human participants is reviewed by a committee called the *Institutional Review Board (IRB)* which works to protect your rights and welfare. If you have questions about your rights, an unresolved question, a concern or complaint about this research you may contact the IRB office at 701.231.8995, toll-free at 855-800-6717 or via email (ndsu.irb@ndsu.edu).

Documentation of Informed Consent:

You are freely making a decision whether to be in this research study. Signing this form means that

1. you have read and understood this consent form
2. you have had your questions answered, and
3. you have decided to be in the study.

You will be given a copy of this consent form to keep.

You understand that the DXA examination is an X-Ray procedure. _______ (Initial)

Your signature	Date
Your printed name	Date
Signature of researcher explaining study	Date
Printed name of researcher explaining study	

APPENDIX H. DXA PRESCREENING QUESTIONNAIRE

Prescreening Questionnaire for DXA procedure

Name (print):_______________________________________ Date: ________________

Is there a chance that you are pregnant? Yes No
Have you had a barium X-ray in the last 2 weeks? Yes No
Have you had a nuclear medicine scan or injection of an X-ray dye in the last week? Yes No
Have you had hyperparathyroidism or a high calcium level in your blood? Yes No

1. Your: Age: ____ Sex: Male Female
2. Your ethnicity (check one):
   __Caucasian (White) __Black __American Indian __Asian __Hispanic __Other
3. Have you ever had a bone density test? Yes No
   If YES, when and where? ____
4. Have you had a recent weight change? Yes No
   If YES, tell us about it: ____
5. Your tallest height (late teens or young adult): ______________
6. Have you ever broken a bone? Yes No

Bone broken	Simple fall?	If not a simple fall, please describe the circumstances	Age when this occurred

7. Has a parent or sibling had a broken hip from a simple fall or bump? Yes No
8. Has a parent or sibling had any other type of broken bone from a simple fall or bump? Yes No
9. How many times have you fallen in the last year? ________
10. Have you ever had surgery of the spine, hips, legs or arms? Yes No
    If YES, describe what type of surgery you had and which side was affected
    ____
    ____
11. Are you currently receiving or have you previously received prednisone pills (cortisone)?
    Yes, currently ____ Yes, previously _____ No ____
    If YES, for how long? ________ What is your dose? _____mg or ______ pills each day
12. Are you currently receiving or have you previously received any of the following medications?

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	No	Yes	For how long?
Medication for seizures or epilepsy			
Chemotherapy for cancer			
Medication for prostate cancer			
Medication to prevent organ transplant rejection			

14. Have you been treated with any of the following medications?

Medication	Ever?	Currently?	If current, how long?
Hormone replacement therapy (Estrogen)			
Tamoxifen (for cancer other)			
Raloxifene (Evista)			
Testosterone			
Etidronate (Didronel/Didrocal)			
Alendronate (Fosamax)			
Risedronate (Actonel)			
Intravenous pamidronate (Aredia)			
Clodronate (Bonefos, Ostac)			
Calcitonin (Miacalcin nasal spray)			
PTH (Forteo)			
Zoledronic acid (Zometa)			
Sodium fluoride (Fluotic)			
Acid reduction (eg Prilosec)			

15. How many servings of the following do you eat/drink per day (on average)?

	Milk (full cup)	Orange juice fortified with calcium (full cup)	Yogurt (small container or ½ cup)	Cheese
Number of servings				

16. Do you take any calcium supplements (including TUMS)? Yes No

17. Do you take any vitamin D supplements (including multivitamins and halibut liver oil)? Yes No

Have you taken calcium or vitamin D today? ***Yes No***

18. Do you smoke? Yes No

For women only…

19. Are you still having menstrual periods? Yes No

20. Before menopause, have you ever missed your periods for 6 months or more, besides during pregnancy? Yes No

21. Have you had your menopause? Yes No
If yes, at what age? ___________

22. Have you had a hysterectomy? Yes No
If YES, at what age? _______
Have you had both of your ovaries removed? Yes No
If YES, at what age? _______

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