August 2016

The Effects of Military Style Ruck Marching on Lower Extremity Loading

Daniel N. Poel
University of Wisconsin-Milwaukee

THE EFFECTS OF MILITARY STYLE RUCK MARCHING ON LOWER EXTREMITY LOADING

by

Daniel Poel

A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Kinesiology

at

The University of Wisconsin-Milwaukee

August 2016

ABSTRACT

THE EFFECTS OF MILITARY STYLE RUCK MARCHING ON LOWER EXTREMITY LOADING

by

Daniel Poel

The University of Wisconsin-Milwaukee, 2016
Under the Supervision of Professor Jennifer Earl-Boehm, PhD

Load carriage while performing prolonged marches may play a role in military overuse injuries. It is known that both external load carriage and muscular fatigue can contribute to increases in ground reaction forces and loading rate and play a role in stress injuries. The purpose of this study is to determine whether or not a prolonged military style ruck march will cause changes in vertical ground reaction force and loading rate. 15 healthy members of the Army ROTC and Army National Guard performed vertical jumps, had ankle dorsiflexion, plantarflexion, inversion and eversion strength measured, and walked across a force plate before and after a 4-mile ruck march wearing full combat gear and a 16kg rucksack. Paired t-tests were used determine if the ruck march caused significant changes in these measures. The pre and post march values of peak vertical ground reaction force ($p<0.005$), loading rate ($p=0.003$), plantarflexion ($p=0.006$), and dorsiflexion ($p=0.01$) strength all changed significantly. It would appear that a relatively short ruck march can elicit significant increases in both vertical ground reaction force and loading rate, while significantly reducing plantar and dorsiflexion strength, all of which are likely factors in the high rate of overuse injuries among military personnel.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

APFT	Army Personal Fitness Test
BW	Body Weight
BW/s	Body Weight per second
DF	Dorsiflexion
EMG	Electromyography
EV	Eversion
EQ	Equivocal
HHD	Hand-Held Dynamometer
HR	Heart Rate
INV	Inversion
Kg	Kilogram
LP	Last Positive
LR	Loading Rate
MRI	Magnetic Resonance Imaging
MVC	Maximum Voluntary Contraction
N	Newton
NEG	Negative
N/sec	Newton's per second
PF	Plantarflexion
PIF	Peak Impact Force
ROM	Range of Motion

ROTC	Reserve Officers Training Corps
RPE	Rate of Perceived Exertion
SMM	Simulated Military Mission
TPSP	Temporospacial Parameters
TT	Talk Test
vGRF	Vertical Ground Reaction Force
VJ	Vertical Jump

Chapter I

Introduction

Background to the problem/question

Stress injuries have been found to occur with relative frequency among both athletic and military populations with approximately 2% of athletes and as many as 40% of basic trainees experiencing bone stress injuries (Hauret, Jones, Bullock, Canham-Chervak, & Canada, 2010; Iwamoto & Takeda, 2003). These injuries often occur secondary to changes in training regimen (Rudzki, 1997). New cadets entering basic training have been found to be at the greatest risk with occurrences 15-23x greater than that of the military population as a whole (Claasen, Hu, & Rohrbeck, 2014; Hauret et al., 2010; Lee, 2011; C. D. Lee, 2011). While rarely life threatening, stress injuries can be debilitating resulting in substantial losses of training hours (Arendt, Agel, Heikes, & Griffiths, 2003; Kupferer et al., 2014), and have been found to be the most significant cause of discharge among military populations resulting in four times as many discharges than any other factor (Trone, Reis, Macera, & Rauh, 2007). While efforts have been made to reduce the rate at which these injuries occur, few have been successful with the exception of a complete reduction in training.

Stress injuries are considered multi-factorial with many modifiable and non-modifiable risk factors. This eclectic combination of factors can be hormonal, physiological, nutritional, or biomechanical, and can range from internal to external causes. While it is probable that these factors vary by individual, it is likely that multiple risk factors interact with one other to initiate the physiologic and biomechanical responses that lead to stress injuries. These risk factors may also be dependent on the population at risk and the environment in which they operate. In the military population, primary risk factors are prolonged intense activity and load carriage. Prolonged intense activity, such as ruck marching while carrying an external load, leads to a decline in physical performance (Gefen, 2002; James, Dufek, & Bates, 2006; C. Milgrom et al., 2007; Wang, Frame, Ozimek, Leib, & Dugan, 2012, 2013). One such measure of a decline in physical performance is a reduction in the muscles ability to perform work or generate force. This has been defined as muscular fatigue (Bigland-Ritchie, 1981; Fallowfield, Blacker, Willems, Davey, & Layden, 2012). The musculature of the lower extremity has been theorized to have a shock absorbing function through eccentric contractions, which may decrease loading forces on the bones of the lower extremities (Verbitsky, Mizrahi, Voloshin, Treiger, & Isakov, 1998; Voloshin, Mizrahi, Verbitsky, & Isakov, 1998; Yoshikawa et al., 1994). This reduction of forces serves to protect the bones and keep loading in a range that minimizes microdamage thus preventing the occurrence of overuse injuries. In the military population muscular fatigue is amplified by three factors, load carriage, low fitness levels, and training load. External load carriage is a common practice in military basic training allowing soldiers to be adequately prepared to carry the equipment needed for their missions. Low fitness levels have also been found in soldiers who have sustained a stress injury, and are another likely cause of muscular fatigue (Beck et al., 2000; Valimaki et al., 2005). Training load is also a likely factor in muscular fatigue. Military personnel must perform rigorous training routines and traverse great distances often on little or no sleep in preparation for the demands of combat.

Military recruits who enter basic training with relatively low levels of aerobic fitness have been found to be at a greater risk of sustaining stress injuries (Cosman et al., 2013).

Further investigation has revealed that compressive bone strength was positively correlated with cross-sectional area of the tibial musculature (Rittweger et al., 2000). When considering the muscles specific to the tibia, reductions of inverter and dorsiflexor maximum voluntary contraction (MVC) may cause significant increases in loading rate (LR), and magnitudes of peak impact force (PIF) as well as ankle joint motion (Christina, White, & Gilchrist, 2001). An electromyography (EMG) study where muscle activity of the gastrocnemius and the tibialis anterior were measured, found greater reductions in MVC in the tibialis anterior then the gastrocnemius causing a reduction in tensile strain of the anterior tibia and increased compression of the posterior tibia, which could result in a stress injury (Mizrahi, Verbitsky, & Isakov, 2000). The magnitude of bone strain and strain rates have also been found to increase with muscular fatigue (Fyhrie et al., 1998) further explaining the relationship between fatigue and stress injuries.

It is likely that much of the lower extremity musculature is instrumental in force mitigation during load bearing activities and that fatigue in any or all of this musculature could result in the greater propagation of forces across bony surfaces. While bone is capable of supporting large loads, the frequency and rate at which loads are applied during military training is cause for concern. Wang and colleagues (2012) examined the effects of load carriage on vGRF and LR during walking to find that fatigue caused increases in both measures, however the fatigue protocol primarily utilized the Queens College step test, and was unlikely to incite fatigue similar to that of a military task (Wang et al., 2012). Due to the likely task specific effects of fatigue it has been recommended that when studying its effects, it is necessary for fatiguing tasks to be as close as possible to real-world situations (Weir, Beck, Cramer, & Housh, 2006).

The effects of external load carriage have been examined, and may contribute to decreased physical performance. Like muscular fatigue, the effects of external load may be magnified in new recruits who enter boot camp with low levels of fitness. EMG studies demonstrated decreased activation of the knee extensors and ankle plantar flexors in infantrymen after performing a simulated military mission (SMM) (Grenier et al., 2012). Bone strain studies during load carriage showed significant increases in compressive strain and strain rate in the second metatarsal bones of soldiers following loaded treadmill walking (Arndt, Ekenman, Westblad, & Lundberg, 2002). Alterations in gait parameters have also been observed with the implementation of external load carriage finding increased range of motion about the trunk, hip, and ankle during loaded walking in a laboratory setting (Attwells, Birrell, Hooper, & Mansfield, 2006; Birrell & Haslam, 2009; Majumdar, Pal, & Majumdar, 2010; Wang et al., 2013). Increases in PIF and LR have also been observed in subjects carrying an external load, finding increases to be proportional to that of the load being applied (Birrell, Hooper, & Haslam, 2007), however a prolonged walk was not investigated. Investigators have found external load carriage to have a significant effect on both peak vertical and braking ground reactions forces and loading rates, as well as increased propulsive forces (Majumdar, Pal, Pramanik, & Majumdar, 2013; Wang et al., 2012). Further inquiry yielded support for external load causing increases in hip and knee extensor moments, and increased ankle joint power absorption(Wang et al., 2013). Increases in maximum vertical and braking GRF as well as in anteroposterior propulsive forces, as compared to unloaded trials, have been observed with load carriage along with increases in maximum hip positive power and knee extensor torque, and increased plantar flexor torque and positive power(Krupenevich, Rider, Domire, & DeVita, 2015).

The combined effects of prolonged marching and load carriage likely lead to earlier or increased performance decrements in military cadets. While the effects of prolonged marching and external load carriage on PIF and LR have been studied, little is known about how these factors interact or the effect they may have on PIF and LR in response to ruck marching, a common training practice during military basic training. Studies that have examined changes in PIF and LR have done so only after an exercise protocol designed to elicit muscle fatigue, but were not ecologically valid when compared to what military cadets endure. Military basic training has been found to cause a higher percentage of bone stress injuries than in any other population with prolonged marching and external load carriage being two likely causes for the high rate of occurrence.

Statement of Purpose

The purpose of this study is to determine: 1) The effects of a prolonged military style march with load carriage on lower extremity loading and muscle strength, and 2) The baseline physical characteristics are related to changes in lower extremity loading following a prolonged march. The above objectives will be met through the following specific aims:

Specific aim 1: To examine differences in peak impact force, loading rate, vertical jump, and dorsiflexor, plantarflexor, invertor, and evertor strength before and after a prolonged military style march with load carriage.

Hypothesis: That post-march peak impact force will be greater than pre-march measures. Likewise, post-march loading rate will increase when compared to pre-march measures. Vertical jump (VJ), and dorsiflexor (DF), plantarflexor (PF), invertor (INV), and evertor (EV) strength will decrease post-march.

Specific aim 2: To determine perceived and physiologic levels of exertion during and at the end of a prolonged military style march.

Hypothesis: Rate of Perceived Exertion (RPE), heart rate (HR), and talk-test (TT) scores will increase as the march progresses.

Specific aim 3: Collect exploratory information to describe differences in participants with different amounts of change in their PIF and LR. Measures of HR, RPE, TT, dorsiflexor, plantarflexor, invertor, and evertor strength, and vertical jump, stride length, cadence, velocity, Army personal fitness test scores (APFT), age, gender, height, and weight will be used to explain these changes.

Delimitations of the study

1. Only cadets of the Army Reserve Officers Training Corps (ROTC) and Member of the U.S. Army reserve were included in this investigation so generalization beyond this population cannot be made.
2. Data were collected in a temperature controlled environment

Assumptions of the study

1. We are assuming that subjects differing boot styles will not cause any significant alterations in PIF of LR measures.
2. We are assuming that that all subjects put forth sufficient effort during the ruck march.

Limitations of the study

1. The main outcome measures are PIF and LR, which are not direct measures of bone loading.
2. Participants were permitted to wear their own footwear.

Significance of the study

Practically applied, this study demonstrates how ruck marching alters lower extremity loading and allows for the speculation of possible causes for those alterations.

Scientifically this study provides further information on two risk factors commonly noted in military stress injuries, and will inform further research on military injuries.

Definition of terms

Fatigue: This term has been used with great variation in the literature. In Chapter 2, when the term is used it will be defined as it has been in the cited study.

Muscular fatigue: will defined as a reduction in the force producing capability of a muscle.

Stress injury: will be defined as localized bone pain of the lower extremity, which increases in severity over time when physical activity is not reduced.

Ruck march: will be defined as a military march performed while in full combat gear, including a ruck sack, vest, and helmet.

Chapter II

Review of the Literature

Epidemiology

Typically found in endurance athletes and the military population, stress fractures are among the most commonly sustained injury type within these populations. When compared to total incidence of injury in military populations it was found that stress injuries account for as few as 1.9% or as many as 40% of total injuries (Hauret et al., 2010). Figure 1.1 Presents the rate at which stress injuries occur compared to that of other fractures. This wide range of occurrence is likely due to the level of military training, given that new recruits entering basic training are more likely to sustain a stress injury then those who have already completed this training. This discrepancy could also be explained by delayed reporting of the injury by soldiers, considering that an injury with great enough severity could result in repeating some or all of basic training or even receiving a medical discharge if the injury is severe enough.

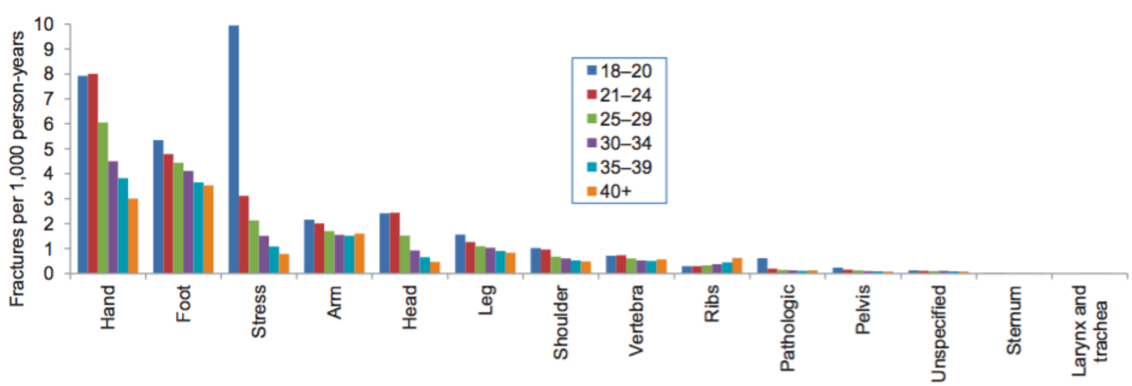


Figure 1.1 Rate of stress fracture occurrence relative to other fractures (Claasen et al., 2014)

When looking at overuse injuries, stress injuries were found to comprise 7.5% of all overuse injuries (Potter et al., 2002). Stress injuries among athletic populations of varying ages and skill levels have been reported on the lower end of that spectrum when compared to military populations (0.8% to 1.9%) (Arendt et al., 2003; Changstrom, Brou, Khodaee, Braund, & Comstock, 2015; Iwamoto & Takeda, 2003). Lower extremity stress injuries were found to occur more frequently than those of the upper extremities, with tibial stress fractures being the most common across all samples. Military injury surveillance has shown stress fracture occurrence to vary widely based on age, gender, and training status, with the total incidence ranging from 2.7-3.24 per 1,000 person years, however incidents rates among new recruits ranged from 39.7-43.75 per 1,000 person years (Claasen et al., 2014; Lee, 2011). Table 1. Expresses common injury and location as well as the type of injury sustained at each location.

Table 1.1 *Injury type and location (Hauret et al., 2010)*

Injury Location	Inflammation and pain (overuse)	Inflammation/pain with nerves (overuse)	Stress Fracture	Sprains/strain/ rupture	Dislocation	Other Joint derangement	n	% total
SPINE AND BACK								
Vertebral Column								
Cevical	24,871	4,249	0	0	0	3,208	**32,128**	**6.0**
Thoracic/dorsal	0	5,698	0	0	0	338	**6,036**	**1.1**
Lumbar	78,750	6,120	0	0	0	10,955	**95,825**	**17.8**
Sacrum coccyx	3,216	0	0	0	0	0	**3,216**	**0.6**
Spine, Back unsecified	20	1,303	177	0	0	3,423	**4,923**	**0.9**
EXTREMITIES								
Upper								
Shoulder	57,416	0	0	1,990	1,641	4,758	**65,803**	**12.3**
Upper arm, elbow	12,535	0	11	0	20	195	**12,761**	**2.4**
Forearm, wrist	11,815	0	22	0	14	505	**12,356**	**2.3**
Hand	6,820	0	0	502	41	206	**7,569**	**1.4**
Lower								
Pelvis, hip, thigh	16,016	0	106	192	12	283	**19,609**	**3.7**
Lower, Leg, Knee	124,648	0	5,449	8,017	358	12,989	**151,461**	**28.2**
Ankle, foot	86,119	0	0	240	114	4,545	**91,018**	**16.9**
Unclassified by site								
Other specified/multiple	3,019	0	271	55	9	147	**3,501**	**0.7**
Unspecified site	23,113	2,585	4,754	303	11	183	**30,949**	**5.8**
Total	**451,158**	**19,955**	**10,790**	**11,299**	**2,220**	**41,733**	**537,155**	
% total	**84.0**	**3.7**	**2.0**	**2.1**	**0.4**	**7.8**		

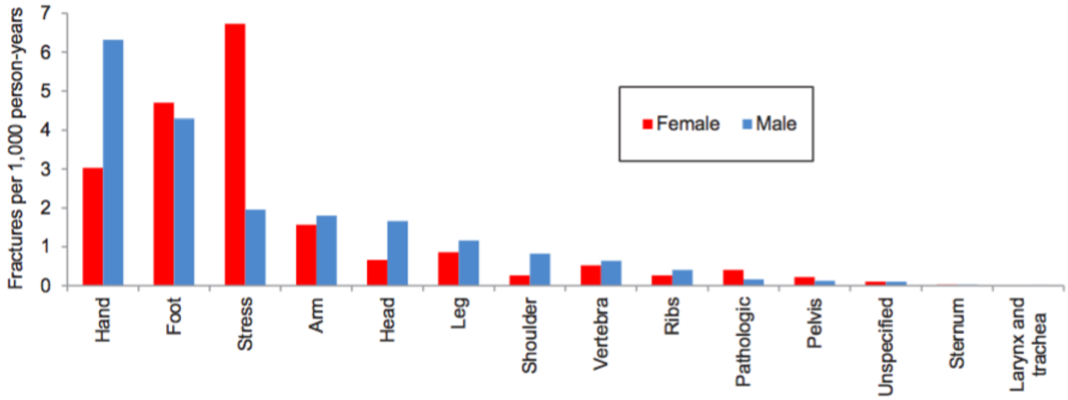


Figure 1.2 Stress Fracture Occurrence by gender and location (Claasen et al., 2014)

Age was also shown to increase the risk of stress injuries in new recruits, and females were found to be at a greater risk then males regardless of training status. Figure 1.2 depicts the incidents of fracture comparing male and female military personnel (Claasen et al., 2014; Lee, 2011).

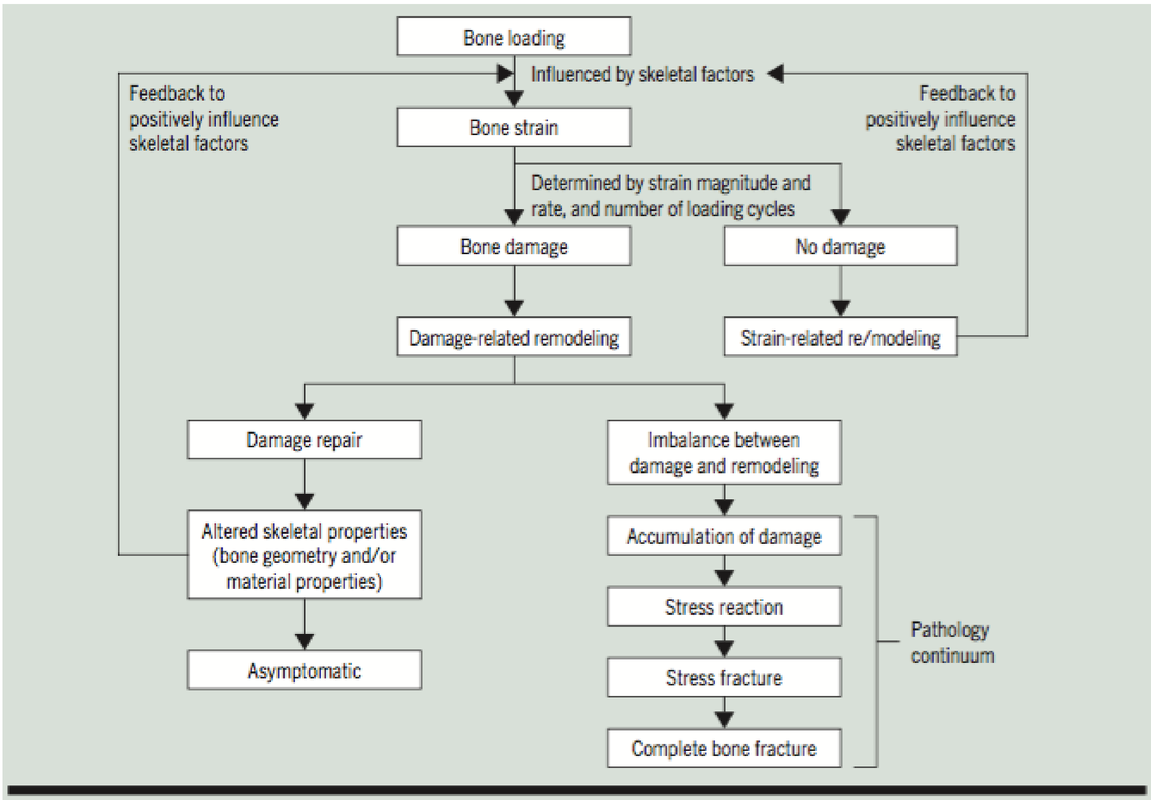
While the rate of occurrence is relatively low, the impact of this injury is significant. The long recovery time of this injury has been found to have a significant effect on military attrition, as well as the $16,000 cost of discharging a new recruit which does not include the cost of any medical treatment they may receive before or after discharge as a result of their injuries (Snoddy & Henderson, 1994). Among Air Force recruits, femoral neck stress fractures comprise 2% of reported stress fractures within the Air Force, but 10% of all lost training days, and cost over $100,000 per incidence (Kupferer et al., 2014). (Arendt et al., 2003) found that the mean time for full return to play for a collegiate athlete was 8.4 weeks after diagnosis, and that there was a direct relationship between the severity of injury and time to return to play. Among military populations, stress injury occurrence has been shown to be the most powerful predictor of discharge among basic trainees, finding that those who have sustained a stress injury are over four times more likely to be discharged than their un-injured counterparts (Trone et al., 2007). In addition to the increase in discharge rate, a similar study found that recruits who sustained a stress injury were more likely to sustain subsequent stress injuries which could multiply the likelihood of discharge exponentially (Milgrom, Giladi, Chisin, & Dizian, 1985). In spite of its relatively low occurrence, the impact of bone stress injuries on military attrition is significant enough to warrant an investigation for the purpose of gaining a greater understanding of military stress injuries, and what can be done to prevent this problem from continuing.

Pathology

The precise mechanism of bone stress injuries is not well understand however, the generally accepted theory is that loading and straining of the bony structure creates an imbalance between the rate at which tissue damage occurs, and the rate that damage is removed. When a bone is loaded, a strain or deformation of the structure may occur, activating cells that remodel the structure, allowing it to better withstand future loads. Skeletal loading can result from a variety of daily activities, with a range of loads and strains experienced throughout these activities. The amount of strain a bone is placed under is contingent upon the overall force generated by a load, the rate at which a load is applied, and the ability of a bone to resist the deformation caused by a combination of these factors (S. J. Warden, Davis, & Fredericson, 2014).

A model of the proposed theory for the pathoetiology of stress injuries and how bone responds in various loading conditions is helpful to guide understanding of this area. Warden et, al. (2006), proposed a model (Table 1.2) that illustrates how a bone responds to the loads and strains placed on it and how they interact to facilitate bone remodeling creating a stronger bone that is better equipped to resist the forces applied to it, as well as how those forces may result in the partial or complete failure of the bony structure.

Table 1.2 *Pathoetiological Model for Stress Injuries (Warden, Burr, & Brunker, 2006)*



Bone remodeling is a constant process, which ensures that a bone has the optimum strength to mass ratio for the tasks it is required to do. Osteoclasts are activated when forces are applied to the bone in order to remove bony tissue that has been damaged, these cells are then followed by osteoblasts which lay down new bone to reinforce its structure (Fyhrie et al., 1998). This allows the bone to become stronger and to better withstand the forces being placed on it. Remodeling is a cyclical process that is constantly shaping bones throughout the body to strengthen weak areas, removing old tissue and laying down new tissue allowing it to respond more favorably to daily activities (S. J. Warden et al., 2014).

Bone strain can also cause tissue damage if the magnitude or rate at which a strain is applied is greater than the bones ability to withstand it. An approximate threshold for the amount of strain cortical bone can withstand during running has been estimated to be between 417 and 2456 $\mu\varepsilon$ (Bayraktar et al., 2004). Strains at or below this value are likely to result in the cyclical remodeling process described above, whereas strains above this value may cause microdamage to the tissue. Once the strain threshold is reached, microdamage will begin to form causing even greater strain on the tissue (Burr, 2002). The accumulation of microdamage is considered to be a normal function of bony tissue, helping it to absorb energy that may cause fractures, and stimulating targeted remodeling of the tissue (Plotkin, 2014).

Targeted remodeling refers to remodeling that occurs in a specific area where microdamage is present. Osteoclasts are activated to resorb tissue in the damaged areas while osteoblasts lay down new tissue to repair and strengthen the damaged tissue (Plotkin, 2014). This process typically reinforces the structure at the same rate as damage occurs, while maintaining the homeostasis of the tissue. While remodeling is taking place there is a period of time between osteoclastic resorption and osteoblastic formation that creates a localized reduction of bone mass, reducing the bones ability withstand the load being placed on it, making the bone highly susceptible to injury during this time (S. J. Warden et al., 2014).

Bone stress injuries occur when microdamage begins to accumulate more rapidly than the bone can be repaired. This can progress from a stress reaction, to a stress fracture, to a complete fracture if proper treatment is not provided. The beginning stages of a stress fracture are known as a stress reaction. Symptomatically, stress reactions present as a gradual onset of localized pain, which can become more severe with weight bearing activity (Fredericson, Bergman, Hoffman, & Dillingham, 1995). Pain with palpation, localized swelling, or warmth, may also be present in symptomatic individuals. A detailed patient history should be taken of persons presenting with these symptoms, inquiring about any recent changes in activity level, running surface, worn out footwear, malnutrition, or menstrual irregularity in female patients (Harrast & Colonno, 2010). A plain radiograph will likely be the first diagnostic test ordered, new bone formation or endosteal thickening found on radiographs may indicate the presence of a stress reaction, however this form of imaging is not often sensitive to such injuries (Daffner & Pavlov, 1992). Scintigraphy may be able to confirm the presence of a stress reaction by detecting accelerated remodeling, however it will not allow clinicians to determine the specific injury location (Haverstock, 2001). Increased bone turnover as well as periosteal and, or marrow edema are the two primary indicators of stress reaction. The most accurate method for detecting the presence of a stress reaction is through magnetic resonance imaging (MRI) (Groves, Cheow, Balan, Bearcroft, & Dixon, 2005; Lee & Anderson, 2004). MRI is the most specific and sensitive imaging tool for diagnosing stress injuries across the spectrum of severity, and can aid in classifying varying degrees of both stress reactions, and stress fractures (Fredericson et al., 1995). Stress reactions can however, be misdiagnosed by MRI when proper radiographs and risk inventories are not also taken.

Stress fractures are the next stage in the progression of overuse bone injuries. They are differentiated from stress reactions by the presence of a visible fracture line, although like stress reactions, these fracture lines are often not visible on plain radiographs, and may require additional imaging (Niva et al., 2007)). Scintigraphy can confirm the presence of a stress fracture but cannot indicate the exact location of the injury, making MRI the gold standard for diagnosing stress injuries. Because MRI's are sensitive to the presence of both stress reactions, and stress fractures, they are often the final step in the diagnostic process when radiographs and, or bone scans do not provide the clinician with enough information for diagnosis and prescription of treatment (Niva et al., 2007)).

When left untreated, stress injuries can continue to progress to total failure of the bone structure resulting in fracture.

Risk Factors

The reasons people sustain stress fractures are considered multi-factorial. A wide variety of external and internal factors have been associated with stress fractures, although the interaction of these factors is not well understood. Furthermore, it is likely that a combination of factors is the cause of injury, with varying factors contributing to injury from one person to another. For the purpose of understanding this complex picture, the individual factors will be discussed.

Hormonal factors play a role in stress fractures by influencing bone growth and turnover. The hormones, estrogen, parathyroid hormone, calcitrol, and thyroid hormones play a significant role in regulating bone growth, while others play a role in maintaining blood calcium levels (Saladin, 1998). Any deviation in these hormones can directly affect bone tissue. Elevated levels of certain hormones have been found to increase the risk for stress injuries. Increased blood albumin and decreased osteocalcin were both associated with decreases in bone thickness possibly contributing to an increased risk for stress injuries (Chatzipapas et al., 2008). Elevated levels of serum parathyroid hormone have also been associated increased rates of bone stress injuries (Valimaki et al., 2005).

Female sex hormones form the linkage to explain why menstrual irregularities have been found to contribute to stress fracture risk. These hormones can inhibit calcium absorption or alter bone remodeling cellular activity. When low levels of estrogen are present bone density is likely to be decreases. Increased risk for bone stress injuries has also been associated with delayed menaracheal age and menstrual irregularities, finding that almost half of all female subjects who reported having a stress fracture also reported menstrual irregularities (Cosman et al., 2013; Korpelainen, Orava, Karapakka, Siira, & Hulkko, 2001; Myburgh, Hutchins, Fataar, Hough, & Noakes, 1990). Females who did not use oral contraceptives were also found to be more likely to have sustained a bone stress injury, which could explain any associated menstrual irregularities (Myburgh et al., 1990). Investigators have recommended closely monitoring women who have not experienced menses within a year as they may be susceptible to increased risk for bone stress injuries (Shaffer, Rauh, Brodine, Trone, & Macera, 2006).

Nutritional and lifestyle factors have also been associated with increasing susceptibility for bone stress injuries. In a cohort of female army recruits, those who reported smoking, consuming ten or more alcoholic beverages per week, or using a corticosteroid, were found to have an increased rate of stress fracture occurrence, finding incidence to be positively associated with the number of exposures (Lappe, Stegman, & Recker, 2001). In Naval recruits, it was found that subjects who sustained a negative energy balance were at a greater risk of sustaining a stress injury for reasons like muscular fatigue, reduction in bone collagen synthesis, and reduced muscular support for bones of the lower extremities (Armstrong, Rue, Wilckens, & Frassica, 2004). Along with total caloric consumption, insufficient vitamin and mineral consumption have been associated with a greater risk for stress fractures. In a group of athletes of varying sports, those who had sustained stress fractures were found to have consumed less calcium than their un-injured teammates, a mineral that has been associated with bone health (Myburgh et al., 1990). Likewise adequate consumption of vitamin D has is inversely associated with stress fracture risk (Sonneville et al., 2012). Subsequent studies have shown that both calcium and vitamin D supplementation may improve bone mineral content and reduce the occurrence of bone stress injuries (Gaffney-Stomberg et al., 2014; McCabe, Smyth, & Richardson, 2012; Miller, Dunn, Ciliberti, Patel, & Swanson, 2016).

Fitness level has been associated to bone stress injuries finding factors such as previous exercise experience, current level of overall fitness, and training regimen all to be associated with stress fracture risk. Previous exposure to exercise has been positively associated with increased bone cross sectional area, finding that military personnel who did not have prior physical activity experience had a lower bone cross sectional area and were more likely to sustain a bones stress injury (Armstrong et al., 2004; Cosman et al., 2013). Further investigation has revealed that those with low levels of fitness are at a far greater risk for stress injury particularly with regards to those just entering basic training (Beck et al., 2000; Valimaki et al., 2005). It has been recommended that female recruits in the Marine Corps. participate in pre-bootcamp physical fitness training to reduce their risk for lower extremity stress fractures, however excessive training loads have also been associated with an increases in the rate at which stress fractures occur (Korpelainen et al., 2001; Shaffer et al., 2006).

Physique factors such as height and weight have been found to be factors in stress fracture risk. Current evidence suggests that there is an optimum height and weight for minimizing the risk of sustaining a bone stress injuries. Both men and women with lower, or higher than average bodyweight, as well as men who are taller on average may be at an increased risk for sustaining a lower extremity stress fracture than those with more moderate body structures (T. J. Beck et al., 1996; J. Knapik et al., 2012; Lappe et al., 2001; Valimaki et al., 2005). Additionally, it has been suggested that women who have a greater proportion of lean body mass could be at a decreased risk for stress fractures (Farr, Chen, Lisse, Lohman, & Going, 2010).

Musculoskeletal structural and biomechanical factors including bone density, geometry, and skeletal alignment have all been investigated for their role in bone stress injuries. Bone density is a key component in stress injuries finding that individuals with lower bone density are likely to incur a bone stress injuries (Cosman et al., 2013; Myburgh et al., 1990; Valimaki et al., 2005). Measures of bone geometry have also been associated with an increased risk for stress injuries. In both men and women, lower bony strength (section modulus), has been found more frequently in subjects who have sustained a stress injury (Franklyn, Oakes, Field, Wells, & Morgan, 2008). Those with a larger bone cross-sectional area are less likely to sustain a stress injury, while those with a weaker tibial diaphysis or a more narrow tibial axis are more likely to sustain a stress fracture when compared to uninjured subjects (Beck et al., 2000; T. J. Beck et al., 1996; Giladi, Milgrom, Simkin, & Danon, 1991). While these factors may be related to increased risk, they are difficult to assess in routine exams and are fairly difficult to change.

Skeletal alignment as well as abnormal joint range of motion can be risk factors for stress injury. Differences in leg length, excessive forefoot varus, and excessively high or low arches have all been associated with bone stress injuries, which have been found to alter loading or gait, and cause abnormal tissue strain (Barnes, Wheat, & Milner, 2008; Korpelainen et al., 2001). In healthy individuals, malalignment is typically brought on by physical exhaustion of some sort, causing significant alterations in skeletal loading. When fatigued, the hip and ankle have been found to assume more extended positions causing loads to be dissipated across bone rather than eccentrically absorbed by muscles (Clansey, Hanlon, Wallace, & Lake, 2012). Increased hip external rotation and abduction range of motion (ROM) as well as rear foot eversion have also been positively associated with stress fractures, finding that subjects with an above average ROM during these movements were more likely to have previously sustained a stress fracture (Giladi et al., 1991; Pohl, Mullineaux, Milner, Hamill, & Davis, 2008).

The musculoskeletal system plays an important role in preventing bone stress injuries. The forces sustained by the bones during load bearing activities are greatly reduced by muscular activity in the lower extremities, particularly during energy absorbing eccentric contractions. Studies in both military personnel and runners have found increased impact and reduced control of the lower extremities when the participants were in a fatigued state, providing support for the theory that muscles are an important mechanism for reducing bone loading (Clansey et al., 2012; Mizrahi et al., 2000). Increased muscle mass has also been linked to higher fitness levels and greater bone cross sectional area suggesting that stronger and more fit individuals will be less likely to sustain lower extremity stress injuries (Beck et al., 2000; Popp et al., 2009).

Extrinsic factors associated with stress injuries include the surface or terrain the body must interact with during activity, footwear, and external loading. Training surface may have some effect on stress fractures risk when considering harder surfaces may have lesser force mitigating properties, or that unstable surfaces may require greater stabilization from the lower extremity musculature expediting the fatigue process, or causing abnormal loading. Research in this area remains inconclusive allowing the contribution of surface to stress injury risk to remain unknown (Brunet, Cook, Brinker, & Dickinson, 1990; Macera, Powell, Jackson, Kendrick, & Craven, 1989; C. Milgrom et al., 2003; Walter, Hart, McIntosh, & Sutton, 1989).

Footwear, and shoe insoles have been studied for their relationship to bone stress injuries, as well as for potential methods of preventing stress injuries. When investigating the force mitigating properties of various running footwear, there appears to be some evidence to support barefoot running with a forefoot-strike pattern for reducing ground reactions forces, although current research remains largely inconclusive (Cheung & Rainbow, 2014; Divert et al., 2008; Giandolini et al., 2013; Thompson, Gutmann, Seegmiller, & McGowan, 2014). It is likely that the forces are concentrated differently causing reduced loading on the tibia, but increased loading on the metatarsal bones, rather than creating a total reduction in force (Salzler, Bluman, Noonan, Chiodo, & de Asla, 2012). Current research would suggest that that the best method of reducing stress fractures through footwear is to make sure the footwear used for physical activity is not worn out (Gardner, Dziados, Jones, & Brundage, 1988). Studies investigating the use of insoles for stress injury reduction indicate that they are not an effective prevention method (Ekenman et al., 2002; Gardner et al., 1988; House, Reece, & Roiz de Sa, 2013).

Load carriage is a factor that is unique to military populations. Due to the nature of their duties, military personnel are often required to walk long distances on varying terrain while carrying heavy packs. External loading has been found to alter a variety of physiological and biomechanical components linked to bone stress injuries. It has been shown that load carriage of varying weights has a significant effect on lower extremity kinematics causing a decrease in ROM about the knee in the sagittal plane, as well as increased hip ROM in the transvers plane, increasing pelvic tilt and rotation, while decreasing stride length (Birrell & Haslam, 2009). Similar studies investigating the effect of varying loads on kinetics found that GRF parameters increased proportionally to the load being carried (Birrell et al., 2007). In both scenarios external loading was found to have significant effects on gait mechanics, posing a significant problem in persons who are not accustomed to carrying an external load, possibly causing the abnormal loading and altered skeletal alignment. Further investigation on the effects of both load carriage and fatigue on bone strain indicates that the interaction of these two factors results in substantial bone strain and is a likely factor in the occurrence of tibial stress fractures within military populations (C. Milgrom et al., 2007).

Other factors that have been associated with bone stress injuries include age, gender, and race. Studies of military populations have found that older recruits sustain stress fractures at a greater rate than their younger peers, likely due to decreases bone mineral density that can be experienced with age (J. Knapik et al., 2012; Mattila, Niva, Kiuru, & Pihlajamaki, 2007). There is also evidence to suggest that females are more likely to sustain stress injuries than their male counterparts. When controlled for body mass, females were found to have reduced bone mineral density, and strength, as well as reduced tibial thickness (Evans et al., 2008; Nieves et al., 2010). When investigating race, it has been shown that African Americans are at a reduced risk for bone stress injuries due to geometrical differences in tibial bone (J. Knapik et al., 2012).

While not well documented, certain psychological factors may also be involved with stress fracture risk as well. When considering that military personnel in basic training may be required to repeat any training they have missed or receive a medical discharge as the result of an injury, there is significant incentive for them to take a “no pain, no gain” mentality toward an injury. While this may be effective for a time, it could eventually lead to greater pain and a complete fracture when considering bone stress injuries, further prohibiting most types of activity and resulting in a far greater loss of training time.

Identified Knowledge Gap

Of particular interest to the author are the factors of prolonged activity and external load carriage due to the seemingly similar effects that they have on PIF, LR, muscle force production, and bone strain, as well as the modifiable nature of these factors . Fatigue has been shown to be a prominent risk factor in both athletic and military stress injuries. Unique to military populations, it appears as though the implementation of external load carriage plays a significant role in stress injuries among military populations. While there has been some investigation into the effects of these two factors there is currently no body of research, which investigates both prolonged ruck marching and external load carriage specific to military activities such as marching, nor does any study investigate how prolonged marching and external loading effect that must be withstood by the lower extremities.

Biomechanical measuring techniques have been found to be of value when inquiring about the mechanisms of bone stress injuries due to fatigue and external loading. EMG is a tool that allows investigators to quantify muscle contractile activity, and can be used as an estimate for reductions in muscular force production. Utilization of surgically implanted strain gauges have also been found to be valuable allowing investigators to determine the amount of strain a bone must withstand during variations of load bearing ambulation, however this technique poses both ethical and practical challenges and is rarely used. Upon the advent of motion analysis technology, investigators were afforded the ability to track and quantify values of human movement through three dimensional video analysis, allowing for a more detailed understanding of joint angles, and angular velocities, providing information about factors such as fatigue or external loading and the effects they have on gait, possibly resulting in abnormal loading of bones. Lastly, by measuring PIF the equal and opposite force of the ground against the body, investigators are able to quantify how factors such as fatigue or external loading may affect total loading of the skeletal system. A device known as a force plate provides an accurate measure of PIF as well as LR, quantifying the total force of the body on the ground as well as the rate at which that force is applied. By utilizing these measurement techniques, it is possible to improve upon the current level of understanding of external loading and fatigue on skeletal loading and how they interact to increase the risk for bone stress injuries.

Loading

Throughout history, loads that soldiers in the U.S. military are required to carry have increased. Along with the increase in load, musculoskeletal injuries have increased sevenfold in the past 25 years. While it cannot be said with certainty that the increase in load carriage is also the reason for increases in musckuloskeletal injury, it seems reasonable to assume that increases in load are at least part of the problem (Seay, 2015). External load carriage is a risk factor unique to military populations, with military personal carrying loads often exceeding 30% of the soldiers body weight consisting of a helmet, body armor, rifle, additional ammunition, and a ruck sack all without consideration for individual body mass (J. J. Knapik, Reynolds, & Harman, 2004). It seems intuitive that this extra load would substantially increase the total load a soldier must be able to withstand during walking or marching, increasing the amount of strain placed on bone, increasing the rate at which fatigue is accumulated, and altering kinematics, all of which are likely to increase the risk of a soldier sustaining a bone stress injury. Following a 21 hour simulated military mission (SMM), trained military infantrymen carrying a 27kg pack had 10.26% reduction in MVC of the knee extensors and a reduced of plantar flexor activity by 10.76%, as measured with EMG. These low levels of fatigue were accompanied by substantial increases in perceived fatigue, with pre-SMM fatigue rated at 8.2 on average while post-SMM fatigue was 15.9 using the Borg 6-20 RPE scale (Grenier et al., 2012). A similar study also found increases in bone strain with the implementation of external load carriage finding that loads of 20kg can cause significant (p=0.05) increases in compressive strain and strain rate on the second metatarsal bones (Arndt et al., 2002).

External load carriage has also been found to effect lower extremity gait kinematics finding increases in ROM about the trunk, hip, knee, and ankle (Attwells et al., 2006; Birrell & Haslam, 2009; Majumdar et al., 2010; Wang et al., 2013). In both male and female subjects increased trunk lean (11° and 13° respectively) and decreased stride length

(1.3%) have been observed when comparing both loaded and unloaded conditions (Krupenevich et al., 2015).

Increases in PIF and LR, as measured by a force plate, have been observed in subjects carrying an external load, finding increases to be proportional to that of the load being applied (Birrell et al., 2007). Investigators have found external load carriage to have a significant effect on both peak and braking vGRF and LR, as well as increased propulsive forces (Majumdar et al., 2013; Wang et al., 2012). Additional inquiry yielded support for external load causing increases in hip and knee extensor moments, and increased ankle joint power absorption (Wang et al., 2013). When carrying a 22kg ruck, increases of approximately 27% were observed in maximum and braking vGRF as well as in anteroposterior propulsive forces as compared to unloaded trials. Maximum hip positive power (15%) and knee extensor torque (65%) increases were also observed in a loaded condition, along with a 23% increase in plantar flexor torque and a 26% increase in positive power (Krupenevich et al., 2015). This increase in power production could also cause a reduced time to fatigue leading subjects to become fatigued much sooner than in unloaded trials. This is supported by evidence suggesting that external load carriage has also been found to be taxing on the cardiovascular system, and a likely factor of increased muscular fatigue with increases in VO2 and heart rate observed during loaded walking as compared to an unloaded condition (Mullins et al., 2015; Quesada, Mengelkoch, Hale, & Simon, 2000).

Fatigue

Fatigue is another factor commonly associated with stress injuries, and can be defined in many ways to suit the needs of the investigator, although most definitions suggest that fatigue is the state in which an individual can no longer perform a task due to exhaustion (Gandevia, 2001). Fatigue is dependent on a number of physiological, neurological, and psychological factors but the underlying reason for fatigue is to incite a discontinuation of activity before homeostasis within the active system is lost. For individuals who choose to ignore their body's warnings, injury and organ damage may occur (Noakes, St Clair Gibson, & Lambert, 2005).

Muscular fatigue, defined as a reduction of a muscles capacity to perform work or generate force (Bigland-Ritchie, 1981), has been postulated as a mechanism for bone stress injuries. It is thought that muscles attenuate ground reaction forces on bone via eccentric contractions, transferring them across the joints and muscles, reducing the impact that would otherwise be absorbed by bone (Verbitsky et al., 1998; Voloshin et al., 1998; Yoshikawa et al., 1994). With the onset of muscular fatigue, their force mitigating properties are reduced and more of the ground reaction forces are transferred to the bone, which may lead to the degradation of bony tissue. Additionally it has been shown that fatigue can result in alterations of movement mechanics, causing bones to be loaded in ways they are not accustomed to (Wang et al., 2013).

EMG measurement provides investigators with information on the level of muscular fatigue within a muscle as a percentage of maximum contraction, in doing so they can gain a greater understanding of the effects of different activities on muscular contractibility. When evaluating pre-tibial and triceps surae muscles after intensive marching decreases of 36% and 40% of max contraction were observed. These values were input into a 3D biomechanical model, which yielded increases in calcaneal and metatarsal loading by 50% and 36% respectively (Gefen, 2002). Further investigation has revealed that the tibialis anterior may become significantly fatigued (p=0.048) during running while gastrocnemius activity was found to increase significantly (p=0.049), possibly creating an increase in anterior tibial strain (Mizrahi et al., 2000). When running to exhaustion, the gastroc-soleus musculature was also significantly fatigued, finding a reduction of 9%-12% in MVC (Weist, Eils, Rosenbaum, & Doz, 2004).

Fatigue has also been found to effect tibial strain, measured using a strain gauge, increases in strain with muscular fatigue could indicate that tibial musculature may help to mitigate some of the stresses placed on bone during loadbearing activities. When measuring the effects of both running and marching on tibial strain, strain increases of 26% when running, and 29% for marching were observed, with increases in strain rate of 13% and 11% respectively. Compression rates also increased by 9% and 17% for the running and marching conditions respectively (C. Milgrom et al., 2007).

Fatigue can cause alterations in gait resulting in abnormal loading of the skeletal system, another factor found to increase the risk of sustaining a bone stress injury. Fatigue effects on running and marching mechanics have been found to cause increases in hip extension (p=0.046) and ankle plantarflexion (p=0.018), with continued increases in extension and planterflexion throughout the duration of the activity. This increased extension could result in greater tibial bone strain and increase the rate of microdamage accumulation, as evidenced by strain gauge studies (Clansey et al., 2012), with further inquiry yielding similar findings (Pohl et al., 2008; Wang et al., 2013).

Summary

When considering the evidence presented above, it appears as though externally loaded prolonged marching is a significant contributor to increased bone loading. While the contribution of these factors is clear, there is currently little understanding of how they interact within military training, which has been found to be the time of greatest risk for stress injuries among military populations. There is evidence to suggest that external load carriage may result in muscular fatigue, increased bone strain and strain rate, altered gait mechanics, and increased PIF and LR. Likewise, there evidence to suggest that prolonged marching, running, or walking may result in increased bone strain, alterations in gait mechanics, and increases in PIF and LR as a result of fatigue. While the parallels between these two factors are evident, the combined effect of these two factors is not well understood. Current investigations of fatiguing exercise and load carriage are somewhat limited in that they neglect key factors unique to military training. Wang et al., (2012; 2013) found that kinetics and kinematics during walking with load carriage were significantly different following a fatiguing exercise bout. However, the use of a Queens College step test to elicit fatigue is not the same type of exercise as a more ecologically valid prolonged ruck march. Furthermore, this study used healthy university males as opposed to subjects with military training. The extent to which a prolonged military style march causes physiological or neuromuscular fatigue is currently unknown. In order to understand how loaded ruck marching may cause fatigue and how that may influence lower extremity loading, investigations must include a ruck marching task and a military population accustomed to that type of activity.

Chapter III

Methods

Experimental Design

Within subject, repeated measures design in a laboratory and indoor track setting. A descriptive design is also used to explore which pre- or post-test measures best describe individuals who had large, small, or no changes in loading after the ruck march.

Participants

Stress injuries occur more frequently in military populations than in any other groups (Changstrom et al., 2015; C. D. Lee, 2011), of those, new recruits entering basic training have been found to be at greatest risk. For that reason, participants were recruited from the Army ROTC of two large Universities who undergo weekly training and have been shown to be at fitness levels similar to that of basic trainees (Thomas, Lumpp, Schreiber, & Keith, 2004). Additional participants were recruited from local U.S. Army reserve units.

An a priori power analysis was performed to identify the sample size needed to using an $\alpha = .05$, and $\beta = .20$, indicated that 15 participants would be needed to adequately protect against type I and type II errors with respect to peak impact force measure, and 21 participants would be required for the loading rate and vertical jump measures. No previous data could be found on changes in ankle strength assessed via hand-held dynamometry in an active population. Based on this analysis, a sample of 23 participants were recruited to account for potential attrition. As Aims 2 and 3 are more exploratory in nature an a priori power analysis was not performed.

Participants were 15 members of the Army ROTC and Army reserve, with a distribution of 10 males, and 5 females based on the University ROTC population being studied (69% males and 31% females). Participants were at least 18 years old with no current injuries that would limit their training. Participants were recruited through the ROTC office, direct emails, and flyers. All participants were physically active and had substantial ruck marching experience.

Instrumentation

Ground reaction force data and vertical jump height were collected using a Bertec force plate model #FP460-NC (Columbus, OH), at a sampling rate of 1000Hz as described in similar studies (K. M. Simpson, Munro, & Steele, 2012). Vertical jump heights were calculated using the same equipment and sampling rate. GaitRite Portable Gait Analysis System (CIR Systems, Franklin, NJ) was used to collect temporospatial parameters. Heart rate (HR) data was collected with a Polar FS1 heart rate monitor (Polar, Lake Success, NY). RPE was collected using the 6-20 Borg scale. Dorsiflexion, plantarflexion, inversion, and eversion max strength was collected using a hand held dynamometer (HHD) (Lafayette Instruments, Lafayette, IN). During the ruck march and collection of force data, participants carried a standardized 16kg U.S. military field pack while wearing a standard military helmet (1.53±0.07kg) and vest (3.65±0.28kg), with their own combat boots, which meet minimum military standards.

Procedures

Pre-march measures:

Demographic information was collected prior to the ruck march and included: Age, height, weight, injury history, footwear type, Years of ROTC or Military service, participation in other Military sponsored events, and APFT scores, which were obtained from the ROTC office or verbally reported by the participants. HR maximum was determined by the formula (220-age) (U.S. Army Training Handbook, 2003). Participants were asked to wear their military uniform for data collection. Baseline data for plantarflexion, dorsiflexion, inversion, and eversion strength were collected with a HHD on the dominant foot. HHD has been found to be a reliable measure of strength when used by experienced practitioners (Bohannon, 1986). The primary investigator completed multiple practice trials of the four strength measures collected prior to data collection to ensure the reliability of the data. For this measure participants were asked to remove the boot and sock from their dominant foot. Three trials for each measure were performed taking the mean of the three trials. Participants were asked to lie supine with the ankle in plantar flexion and hips and knees extended. When measuring plantar flexion strength the HHD was placed over the metatarsal heads on the sole of the foot. Dorsiflexor strength was measured with the HHD on the dorsum of the foot over the metatarsal heads. Inversion strength was measured by placing the HHD on the medial side of the foot over the first metatarsal head. Eversion strength was measured by placing the HHD on the lateral side of the foot over the fifth metatarsal head (Mentiplay et al., 2015). While the researcher provides manual resistance, participants were asked to contract isometrically against the HHD for 5 seconds, with 10-30seconds rest between trials (Bohannon, 1986). The tester stabilized the lower leg proximal to the ankle joint to ensure muscle isolation. Three trials for each measure were recorded, and the average was used for analysis.

To quantify muscular power output before and after the march (as a measure of muscular fatigue), maximum VJ heights in meters were collected from participants jumping on the force plate. Participants were instructed to rapidly descend to a half-squatting position while simultaneously extending their arms back, spending as little time as possible in the squatting position they were asked to rapidly extend their legs while throwing their arms in an upward direction, jumping as high as they could. To warm up, a light 5-min jog was performed followed by 2-4 practice jumps to check for proper technique, followed by three trials for each participant, recording the highest of the three jumps.

Secondary data was collected from participants APFT, including number of push-ups in 2 minutes, number of sit-ups in 2 minutes, and 2 mile run time. Soldiers performing these tasks are allowed a minimum of 10 minutes and a maximum of 20 minutes rest in between each task, but must complete all three tasks in 2hr. Tests are scored on a 100pt scale for a maximum score of 300. Soldiers must attain a minimum score of 60pt on each test for a total of 180pt while those in basic combat training must attain a minimum score of 50pt on each test for a total score of 150pt. Scoring is adjusted for age and gender (Army Physical Readiness Training, 2012) (APFT scoring charts in appendix F).

Resting HR was collected by having participants lie supine for 5 minutes and was established prior to any other baseline testing to minimize any potential increase in HR. Participants were wearing one of several models of military approved boots, their personal helmet (1.53±0.07kg), and vest (3.65±0.28kg), and a standardized U.S. military field pack weighing 16kg, which was adjusted to fit the individual for their comfort. Force data was collected with participants walking across a force plate. Participants were required to repeat this process until 5 successful trials are recorded. Trials were considered successful when a participant's entire foot (dominant) struck the force plate in stride with no alterations in gait with a velocity of 1.79±0.25 m/s.

Participants were familiarized with the RPE 6-20 Borg scale and talk test after collection of the force data. For the RPE emphasis was placed on verbal anchoring, using examples of physical activity that would correspond to numerical values on the RPE scale (e.g. an RPE of 6 would be no exertion "little or no movement, relaxed") (Borg, 1982).

As another measure of physical exertion, the talk test (TT) was used to estimate ventilatory thresholds, which are the points during exercise at which the increase of one's ventilation rate becomes non-linear (Plowman & Smith, 2014). For the TT, participants were instructed to recite the "Pledge of Allegiance" at the end of every 4th lap and again on the final lap and respond to the question "Can you speak comfortably." Participants were instructed to answer "YES" (indicating they are below their ventilatory threshold), "YES BUT…" (indicating they are nearing their ventilatory threshold), or "NO," indicating that they had crossed their ventilatory threshold. HR, RPE, and time from the beginning of the march were recorded at the same time as the talk test (Lyon et al., 2014).

Ruck March:

The protocols for ruck marching vary widely across training groups. While a 12-mile march is considered the Army standard (*FM 7-22 Army Physical Readiness Training*, 2012), the ROTC groups participating in this study have a different standard procedure. The constrained variables in the march task are distance and completion time. Cadets selected their own pace but were asked to refrain from running, and were given a target time of 60 minutes to complete the ruck march. A typical training march is 3 to 5 miles, for this study, it was important to select a march protocol that was challenging to the majority of potential participants. Participants completed a 4-mile ruck march in a 200m indoor track in 60 minutes time. To measure the intensity of the task a research assistant recorded HR, RPE and TT data every 4th lap during the march as well as on the final lap. HR was documented upon the participant's return to the lab.

The GAITRite system was used to collect information about the temporospatial parameters of gait, including stride length, cadence, and walking velocity. Participants walked across the gait mat at the end of every 4th lap during the ruck march as well as on the final lap. These data will be used to further describe the changes that occur in gait while ruck marching, and compared to the known changes that have been reported in the literature.

Upon completion of the march, participants continued at the same pace proceeding immediately to the lab to collect force data, VJ, and ankle strength measures.

Post-march measures:

Participants completed at least 5 additional walking trials immediately after completion of the ruck march, followed by 3 maximum vertical jumps (best of 3 trials will be recorded) and 3 trials each of plantarflexion, dorsiflexion, inversion, and eversion strength (mean of 3 trials will be recorded) following the same procedures described in the pre-march section.

Data Processing

Ground reaction force data was filtered using a 4th order, zero lag, recursive Butterworth filter with a cutoff of 50Hz (Bazett-Jones et al., 2013). The vGRF component was normalized to participant's body mass(kg) and reported as % body weight, and then averaged across the five recorded trials. Initial contact was defined as when the vGRF component exceeded 20 N, and toe-off was defined as when the same drops below 20 N. The magnitude of the vGRF at the first peak was identified as the PIF. The loading rate (N/sec) was calculated by dividing the PIF by the time from initial contact to PIF and was then normalized to body mass (kg) and reported in BW/S (LR=peak impact force/time to peak impact force) (Majumdar et al., 2010; K. M. Simpson et al., 2012)

Statistical Analysis

All statistical analyses were performed in SPSS v22 (SPSS, Chicago, IL). For Aim 1, a paired t-test was used to determine the effects of ruck marching on PIF, LR, VJ, and plantarflexor, dorsiflexor, invertor, and evertor strength.

For Aim 2 repeated measures ANOVA and Friedman tests were used to compare %HRmax and RPE respectively across the eight time intervals, followed by post hoc Bonferroni and Wicoxon Signed Rank tests respectively to determine the point(s) in time at which these measures became significant. The TT was evaluated by graphing and visually inspecting the data to determine if, and when, participants crossed their ventilatory threshold. An alpha level will be set at 0.05 for all tests.

For the descriptive portion (Aim 3), participants were categorized based on change in vGRF and LR, using PF and DF strength, and APFT scores to evaluate why some participants may have had greater changes in vGRF and LR than others.

Chapter IV

Manuscript

The Effects of Military Style Ruck Marching on Lower Extremity Loading

Poel, D., Ebersole, K.T., Zalewski, K., Earl-Boehm, J.E.,

Introduction

Bone stress injuries (BSI) (e.g. stress reactions, stress fractures etc.) have been found to occur with relatively high frequency among military personnel. New recruits are at the greatest risk, as many reports indicate that as many as 40% of individuals participating in basic training experience a bone stress injury (Hauret et al., 2010; Iwamoto & Takeda, 2003). In new cadets entering basic training the incidence is over 15 times greater than the rest of the military population (Claasen et al., 2014; Hauret et al., 2010; C. D. Lee, 2011). Bone stress injuries are often debilitating and can result in a substantial loss of training hours (Arendt et al., 2003; Kupferer et al., 2014), they have also been found to be the most common cause of discharge among military populations (Trone et al., 2007). While efforts have been made to reduce the incidence of bone stress injuries (Ekenman et al., 2002; House et al., 2013), few have been successful with the exception of a complete reduction in training. Due to the high rate of incidence and the loss of training days associated with bone stress injuries, there is an urgent need to gain a thorough understanding of the factors that contribute to this problem, such as impact forces during common military tasks like ruck marching, so that future research can investigate preventative measures.

Military basic training has been associated with a higher percentage of bone stress injuries than in any other population (Claasen et al., 2014; Hauret et al., 2010; C. D. Lee,

2011) with prolonged marching and external load carriage being two of the likely causes for the high rate of occurrence. Prolonged intense activity, such as ruck marching while carrying an external load, leads to a decline in physical performance (Gefen, 2002; James et al., 2006; C. Milgrom et al., 2007; Wang et al., 2012, 2013). One such measure of a decline in physical performance is a reduction of a muscles ability to perform work or generate force, which can be referred to as muscular fatigue (Bigland-Ritchie, 1981; Fallowfield et al., 2012). The musculature of the lower extremity has been theorized to have a shock absorbing function through eccentric contractions, which decreases loading forces on the lower extremity (Verbitsky et al., 1998; Voloshin et al., 1998; Yoshikawa et al., 1994). This reduction of forces serves to protect the bones and keep loading in a range that minimizes microdamage to bony tissue, thus preventing the occurrence of overuse injuries. A muscle's loss of ability to produce force following prolonged activity may be a contributing factor to BSI.

Military recruits who enter basic training with relatively low levels of aerobic fitness have been found to be at a greater risk of sustaining stress injuries(Cosman et al., 2013). Further investigation has revealed that compressive bone strength was positively correlated with cross-sectional area of the tibial musculature indicating that muscles mass is also an indicator of bone strength(Rittweger et al., 2000). Thus, individuals with lower aerobic fitness and less muscle mass may have even greater performance decrements during prolonged ruck marching. When considering the muscles specific to the lower leg, reductions of invertor and dorsiflexor maximum voluntary contraction (MVC) in female runners have been shown to cause significant increases in loading rate (LR), and peak impact force (PIF) as well as ankle joint motion(Christina et al., 2001). An electromyography (EMG) study, where muscle activity of the gastrocnemius and the tibialis anterior were measured, found greater reductions in MVC of the tibialis anterior than the gastrocnemius, causing a reduction in tensile strain of the anterior tibia and increased compressive strain of the posterior tibia, which could result in a stress injury (Mizrahi et al., 2000). Bone strain and strain rates have also been found to increase with muscular fatigue (Fyhrie et al., 1998) further explaining the relationship between fatigue and stress injuries. This indicates that the ankle musculature may be instrumental in force mitigation during load bearing activities and that fatigue in any of these muscles could result in greater propagation of forces across bony surfaces.

While bone is capable of supporting large loads, the duration, frequency and rate at which loads are applied during prolonged activity is cause for concern. Prolonged running has been shown to cause reductions in the force mitigating properties of lower extremity musculature and increases in PIF and LR, all of which have been linked to bone stress injuries (Bennell et al., 2004; Clansey et al., 2012; Mizrahi et al., 2000; Warden et al., 2006; S. J. Warden et al., 2014). The combined effects of prolonged marching and carrying heavy loads leads to similar performance decrements. Wang and colleagues (2012) examined the effects of load carriage on PIF and LR during walking before and after a fatiguing task. They found that fatigue caused increases in both measures, however the fatigue protocol primarily utilized the Queens College step test, and was unlikely to incite fatigue similar to that of a ruck march task (Wang et al., 2012). In addition, the participants had no experience performing the ruck-march task with the external load. Due to the likely task specific effects of fatigue it has been recommended that when studying its effects, it is necessary for these tasks to be as close as possible to real-world situations (Weir et al., 2006).

While there has been some investigation into the effects of prolonged activity and load carriage (Arndt et al., 2002; Majumdar et al., 2010; C. Milgrom et al., 2007; Wang et al., 2012, 2013), there is currently no body of research, which investigates the effects of prolonged ruck marching and external load carriage on the forces applied to the body. In order to understand how loaded ruck marching may influence lower extremity loading, investigations must include a ruck marching task and a military population accustomed to this type of activity. The purpose of this study was to examine the effects of a prolonged military style march on lower extremity loading, strength, and lower extremity power output. A secondary purpose was to explore the level of exertion throughout a ruck march, fitness level of the participants, and gait temporospatial characteristics to describe the potential changes seen across participants.

Methods

15 Reserve Officers Training Corp. (ROTC) cadets and soldiers of the U.S. Army reserve (10 male, 5 female), age (21.4±2.72yr), body mass (71.52±13.84kg) and Height (1.77±0.11m) participated in this study. Participants were involved in regular physical training, had experience with ruck marching, and were free of any training limiting injuries.

<u>Instrumentation</u>

Ground reaction force data was collected using a Bertec force plate model #FP460-NC (Columbus, OH), at a sampling rate of 1000Hz as described in similar studies (K. M. Simpson et al., 2012). Vertical jump (VJ) heights were calculated using the same equipment and sampling rate. A GaitRite Portable Gait Analysis System (CIR Systems, Franklin, NJ) was used to collect temporospatial parameters (TPSP) of gait during the ruck march. Dorsiflexion (DF), plantarflexion (PF), inversion (INV), and eversion (EV) maximum strength were collected using a hand held dynamometer (HHD) (Lafayette Instruments, Lafayette, IN). During the ruck march and collection of force data, participants carried a standardized 16kg U.S. military field pack while wearing a standard military helmet (1.53±0.07kg) and vest (3.65±0.28kg), with their own combat uniform and boots, which met minimum military standards.

Procedure

Pre-march measures:

Participants reported to a biomechanics lab for one testing session. After consenting to participate, resting heart rate (HR) was established by having participants lie supine for 5 minutes. Demographic information was then collected including: Age, height, weight, injury history, footwear type, years of military service, participation in other military sponsored events, and Army Personal Fitness Test (APFT) scores. APFT scores were obtained from the ROTC office or verbally reported by the participant. Participants were asked to wear their military uniform for the entirety of data collection however the rucksack, vest, and helmet were only worn for the collection of force data and during the ruck march.

Baseline ankle strength was collected with a hand held dynamometer (HHD) on the dominant foot by a single researcher with experience with this measurement. For this measure participants were asked to remove their boot and sock. Two warm up trials of 50% and 75% effort were performed followed by three trials of maximal effort. Participants were asked to lie supine with the ankle in a neutral position and the hips and knees extended. When measuring PF strength the HHD was placed over the metatarsal heads on the sole of the foot. DF strength was measured with the HHD on the dorsum of the foot over the metatarsal heads. INV strength was measured by placing the HHD on the medial side of the foot over the first metatarsal head. EV strength was measured by placing the HHD on the lateral side of the foot over the fifth metatarsal head(Mentiplay et al., 2015). While the researcher provides manual resistance, participants will be asked to contract isometrically against the HHD for 5 seconds, with 10-30seconds rest between trials(Bohannon, 1986). The tester stabilized the lower leg proximal to the ankle joint to ensure muscle isolation, and was leaning against a wall for added stability. The average of the three maximal trials were used for analysis.

To quantify lower extremity muscular power output before and after the march, vertical jumps (VJ) were performed on the force plate. Participants were instructed to rapidly descend to a half-squatting position while simultaneously extending their arms backward, spending as little time as possible in the squatting position they were asked to rapidly extend their legs while throwing their arms in an upward direction, jumping as high as they can. To warm up, a brisk 5-min walk was performed followed by 2-4 practice jumps to check for proper technique, followed by three recorded trials, analyzing the highest of three trials.

The APFT scores for each of the participants were obtained from previous records. The APFT was not part of this data collection protocol, and were collected prior to the study during regular training. These scores were obtained to provide an estimate of the participant's fitness level. The AFPT is comprised of the number of push-ups completed in 2 minutes, the number of sit-ups completed in 2 minutes, and 2 mile run time. Soldiers performing these tasks are allowed a minimum of 10 minutes and a maximum of 20 minutes rest in between each task, but must complete all three tasks in 2hr. Tests are scored on a 100pt scale for a maximum score of 300. Soldiers must attain a minimum score of 60pt on each test for a total of 180pt while those in basic combat training must attain a minimum score of 50pt on each test for a total score of 150pt. Scoring is adjusted for age and gender (Army Physical Readiness Training, 2012) (APFT scoring charts in appendix F).

Participants wore one of several models of military approved boots, their personal helmet (1.53±0.07kg), and vest (3.65±0.28kg), and a standardized rucksack weighing 16kg, which was adjusted to fit the individual for their comfort. Force data was collected with participants walking across a force plate. Participants were required to repeat this process until 5 successful trials were recorded. Trials were considered successful when participant's entire foot (dominant) struck the force plate in stride with no alterations in gait with a velocity of 1.79±0.25 m/s.

To assess physical exertion during the march, the RPE and TT were used in addition to HR. Participants walked to the climate controlled indoor track where they were familiarized with the RPE 6-20 Borg scale and talk test (TT) after the collections of force data was completed. For the RPE, emphasis was placed on verbal anchoring, using examples of physical activity that would correspond to numerical values on the scale (Borg, 1982).

The TT was used to estimate ventilatory threshold, which are the points during exercise at which the increase of one's ventilation rate becomes non-linear (Plowman & Smith, 2014, p. 716). For the talk test, participants will be instructed to recite the "Pledge of Allegiance" and respond to the question "Can you speak comfortably." Participants were instructed to answer "YES" (indicating they are below their ventilatory threshold), "YES BUT…" (indicating they are nearing their ventilatory threshold), or "NO", (indicating that they have crossed their ventilatory threshold)(Lyon et al., 2014).

Ruck March:

The protocols for ruck march training vary widely across training groups. While a 12-mile march is considered the Army standard (*FM 7-22 Army Physical Readiness Training*, 2012), the ROTC groups participating in this study have a different standard procedure. A typical training march is 3 to 5 miles, for this study, it was important to select a march protocol that will be challenging to the majority of potential participants. Participants completed a 4-mile ruck march in a 200m indoor track with a target time of 60 minutes. The constrained variables in the march task are distance and completion time. Cadets can select their pace as long as they complete the prescribed distance in the allotted time, however participants were instructed to avoid running throughout the duration of the task. To measure the physical exertion of the task, HR, RPE and TT data were recorded at the end of every 4th lap, and again at the end of the final lap of the march.

The GAITRite system was used to collect stride length, cadence, and walking velocity information at the end of every 4th lap and again on the final lap of the ruck march. These data were used to further examine the changes that occur in gait while ruck marching, and compared to the known changes that have been reported in the literature.

Upon completion of the march, participants were instructed to maintain their pace and proceed immediately to the biomechanics lab, which was approximately 150m from the indoor track facility. Upon return to the lab, HR was recorded to determine if participants level of exertion had been maintained, and post-march force, VJ, and ankle strength data were collected.

Post-march measures:

Participants completed at least 5 walking trials immediately after completion of the ruck march, followed by 3 maximum VJ (best of 3 trials were recorded) and 3 trials each of PF, DF, INV, and EV strength (mean of 3 trials were recorded) following the same procedures described in the pre-march section. All of these measures were completed within 10 min. of completion of the ruck march.

Data Processing

Ground reaction forces were filtered using a 4th order, zero lag, recursive Butterworth filter with a cutoff of 50Hz (Bazett-Jones et al., 2013). Initial contact was defined as when the vGRF component exceeds 20 N. The magnitude of the vGRF at the first peak was identified as the peak impact force. The vGRF component (N) was normalized to participant's body mass(kg) and reported as % body weight, and then averaged across the five recorded trials. The loading rate (BW/sec) was calculated by dividing the peak impact force by the time from initial contact to peak impact force (LR=peak impact force/time to peak impact force) (Majumdar et al., 2010; K. M. Simpson et al., 2012)

Statistical Analysis

All statistical analyses were performed in SPSS v22 (SPSS, Chicago, IL). A Paired t-test was used to determine the effects of ruck marching on vGRF, LR, VJ, and PF, DF, INV, and EV strength.

A repeated measures ANOVA was used to evaluate changes in %HRM across the eight time intervals, followed by a post hoc Bonferroni test to determine the point(s) in time at which this measure became significant. A Friedman test was used to evaluate the change in RPE followed by a post hoc Wilcoxon Signed Rank test to determine when significant changes in RPE were observed. TT was evaluated by examining if and when participants crossed their VT by an answer of "yes but…" or "no." Significance was set at 0.05 for all tests.

For the descriptive portion, two groups of 4 participants were created based on those who had the greatest change peak impact force, and those who had the least change. APFT scores, HR, RPE, ankle strength, VJ, TPSP's, age, gender, height, and weight were then compared between the groups to evaluate why some participants may have had greater changes in peak impact force than others.

Results

Peak Impact Force and Loading Rate

Participants completed the ruck march in 59min. ±4min. There was a significant increase in peak impact force for all participants following the march resulting in an average increase of 0.12BW±0.088BW ($t= -5.273$, $p<0.0005$). LR also increased significantly with an average increase of 1.995±0.022BW/s ($t=-3.523$, $p=0.003$).

Table 4.1 *Pre and post march values for peak impact force and loading rate reported in body weight and body and body weight/s (*) denotes a significant change.*

Variable	Pre-Mean	Post-Mean	Mean diff.	SD	P-value	T	Effect Size
Peak Impact(BW)	2.071	2.192	0.1204	0.884	<0.0005*	-5.273	0.665
LR (BW/s)	18.41	20.41	1.99	0.022	0.003*	-3.523	0.47

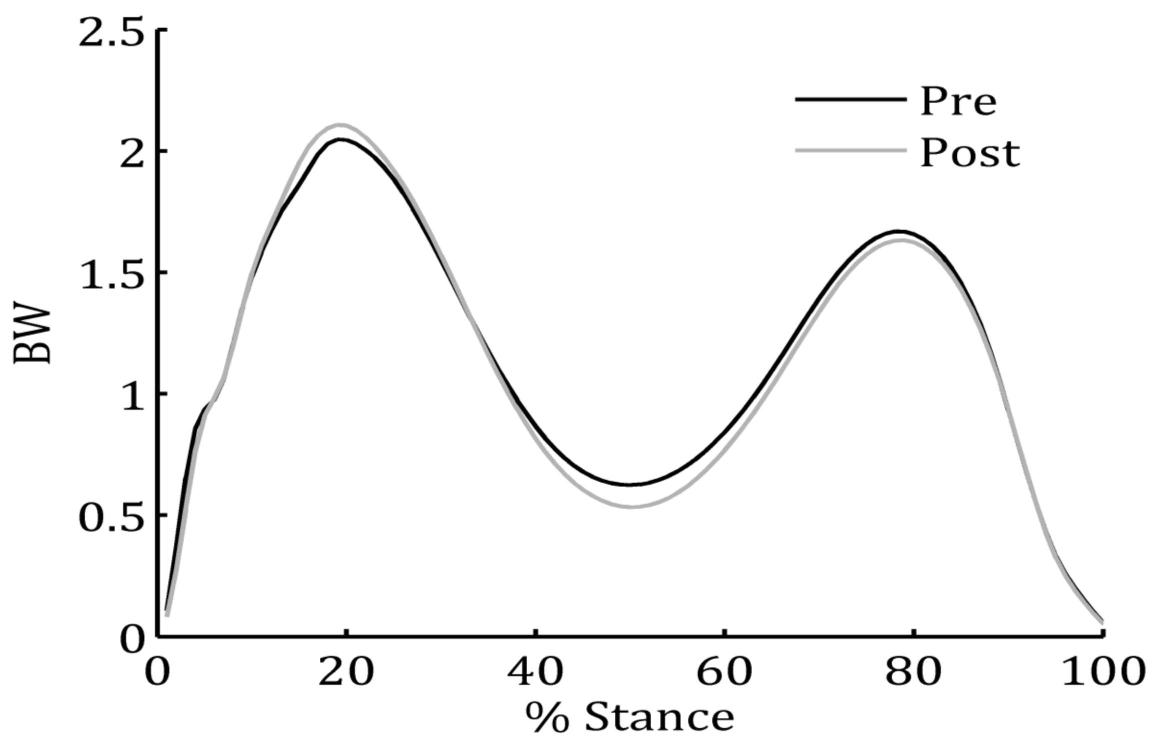


Figure 4.1 Pre and post vGRF reported in percentage of bodyweight, and percentage of stance.

Vertical Jump

There was not a significant change in VJ height (p=0.61) from pre-to-post march with increases in VJ recorded for 6 participants following the ruck march. (Table 4)

Ankle Strength

For ankle strength, DF significantly decreased with an average reduction of 2.58±3.36kg (t=2.977, p=0.01). PF strength also decreased significantly following the ruck march with reductions averaging 4.18±5.04kg (t=3.217, p=0.006). There were no a significant changes observed in either INV or EV strength (t=1.621,p=0.127; t=0.515, p= 0.615) respectively.

Table 4.2 *Pre and post march values for vertical jump and ankle strength measures reported in meters and kilograms. (*) denotes a significant change.*

Variable	Pre-Mean	Post-Mean	Mean diff.	SD	P-value	t	Effect Size
VJ (m)	0.4364	0.4243	0.0121	0.087	0.61	0.523	0.021
INV (kg)	19.327	18.14	1.187	2.836	0.127	1.621	0.158
EV (kg)	21.858	21.476	0.382	2.875	0.615	0.515	0.019
DF (kg)	24.184	21.605	2.579	3.355	0.01*	2.977	0.388
PF (kg)	55.093	50.911	4.182	5.035	0.006*	3.217	0.425

Physical and Perceived Exertion

Measures of exertion taken during the ruck march yielded similar results with %HRMAX increasing from 75.1-83.5% (p=0.013), with a significant change occurring between laps 8 and 12 (p=0.011). RPE increased from 10.8 to 13.5 on average (p=0.072) with significant changes occurring between laps 4 and 8 (z= -2.414, p=0.016), 8 and 12 (z=-2.070, p=0.038, 12 and 16 (z=-2.236, p=0.025), 20 and 24 (z=-2.121, p=0.034), and 24 and 28 (-2.121 p=0.034). Other measures taken during the ruck march including TT, and TPSP’s remained relatively consistent and did not have any significant changes.

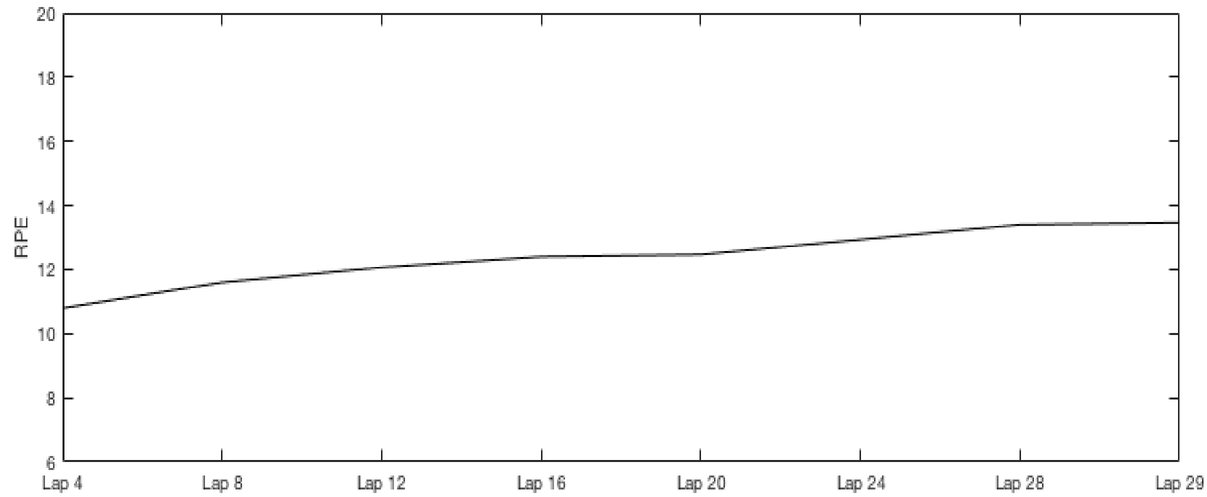


Figure 4.2 Mean change in RPE across the ruck march

Table 4.3 *Temporal special parameters collected at three equally spaced intervals during the ruck mach.*

	Lap 4	**Lap 16**	**Lap 29**
Step Length R(m)	0.846	0.871	0.846
Stride Length R(m)	1.706	1.752	1.69
Velocity (m/s)	1.778	1.84	1.81
Cadence(steps/min.)	125.54	127.36	128.79

Descriptive Variables

For this portion of the analysis, variables were graphed and visually inspected for possible contributions to increased PIF following the ruck march, additional post hoc. analyses were conducted on variables that appeared to be significant contributors to the change in PIF. When considering gender differences between participants, males (0.14±0.01 %BW) were found to have almost double the change in PIF from pre to post march then that of females (0.8±0.046 %BW), with similar differences occurring in LR change between males (2.38±2.53 BW/s) and females (1.36±1.54 BW/s) pre to post march. BW between males (75.16 kg) and females (64.25 kg) differed by about 10 kg, but the 16 kg ruck sack was similar when considering its percentage of participants BW (males (0.22 %BW), Females (0.25 % BW). It was also observed that females HR (11.2 bpm) decreased more then males (4.3 bpm) when comparing participants change in HR from the completion of the ruck march to beginning the collection of post-march measures, while RPE evaluations on the final lap (14, and 13.2) and across the ruck march as a whole (13.2, and 12) were higher in females then males respectively.

When considering the group as a whole, APFT scores appeared to be higher in participants with less of an increase in PIF, however both the low and high PIF groups had an outlier. There were also some trends noted in TPSP's with participants who took longer steps and strides, and who had a faster velocity and lesser cadences producing greater PIF following the ruck march, while participants who took shorter steps and strides and had a slower velocity and a greater cadence demonstrated a smaller change in PIF following the ruck march. VJ did not appear to be different in participants with greater or lesser PIF, nor did any of the ankle strength measures. Participants HR and RPE did not appear to be a factor in increases or decreases in PIF when comparing those with the largest and smallest changes in PIF. Additionally, neither participant's age nor their height appeared to have an effect on their PIF.

Discussion

The purpose of this study was to describe the effects of a military style ruck march on lower extremity loading by measuring changes in PIF and LR before and after a 4-mile ruck march. Additional measures of ankle PF, DF, INV, and EV as well as VJ were taken before and after the march as a way of explaining any changes in PIF and LR that may have occurred. It was hypothesized that there would be an increase in both PIF and LR following the ruck march due to the exhaustive nature of the task. This hypothesis was supported by the results of the study, finding that the ruck march resulted in significant increases of peak PIF and LR, as well as significant strength reductions of the PF, and DF musculature.

Peak Impact Force and Loading Rate

Increases in PIF and LR have been documented following various tasks in both loaded and non-loaded conditions (Christina et al., 2001; Clansey et al., 2012; Wang et al., 2012), many of which have been done in an effort to gain a greater understanding of overuse injuries. While similar in purpose, this study is the first of its kind to evaluate the effects of an ecologically valid marching task on PIF and LR. The results of the current study corroborate what is already known about force changes following prolonged activities of various loads, however the changes in PIF observed in the current study are greater in magnitude then changes in the same measure found in similar studies. Wang and Colleagues (2012), utilized a modified queen's college step test to fatigue college aged males carrying a 32kg ruck sack finding smaller changes (7%) in peak impact force, with a ruck sack of double the weight. These differences could be a function of the of the highly quad dominant fatigue protocol used, whereas the ruck march used in the current study was likely to cause greater reductions in ankle strength. Other publications have evaluated peak impact force and LR before and after bouts of running and or localized muscular fatigue to find significant increases in LR but not PIF (Clansey et al., 2012), or increases in

LR and decreases in PIF (Christina et al., 2001), building further support for the need for an ecologically valid task due to the likely task specific changes in PIF and LR.

It is also worth mentioning that although the changes in PIF and LR were statistically significant, both were below that of female runners who had previously suffered tibial stress fractures. Two publications comparing female runners with and without tibial stress fractures found that injured individuals displayed smaller PIF (0.21 BW) and greater LR (24.96 BW/s) and (23.5 BW/S) when compared to their non-injured counterparts (0.32 BW, 19.52 BW/s) and (22.4 BW/S) respectively. (Milner, Ferber, Pollard, Hamill, & Davis, 2006; Pohl et al., 2008). Furthermore, a prospective study conducted by Davis and Colleagues (2004) found that female runners who later developed a tibial stress fracture displayed greater LR's than those who did not develop an injury (Davis, Milner, & Hamill, 2004). While direct comparisons cannot be made between these and the current study due to the effects of velocity on PIF and LR, this evidence suggests that increases in PIF and LR may result in a tibial stress injury.

An exploratory analysis was conducted to determine if gender differences existed for any of the measures collected during the current study. These analyses revealed that gender differences were present in both PIF and LR. Males exhibited nearly double the change in PIF and LR (0.14 BW, 2.38 BW/s) of Females (0.08 BW, 1.36 BW/s), while BW differed by about 10 kg (male 75.2kg, female 64.3kg) and the weight of the rucksack was similar (male 22% of BW, female 25% of BW), relative to participant BW. Further exploration revealed that females recovered more quickly following the ruck march. The heart rate of female participants decreased by 11bpm in the time it took to walk from the track to the lab for collection of post march measures, while male participants had a HR reduction of about 4bpm in the same amount of time. Furthermore, females (RPE 13.2) rated their overall exertion during the ruck march as higher then that of the male participants (RPE 12). While males perceived the ruck march to be less physically taxing then females who performed the same task, their mechanical and physiological responses to the task would indicate that it was more difficult for males then females.

Ankle Strength

Muscular fatigue, defined as a reduction of a muscles ability to produce force (Bigland-Ritchie, 1981), is another likely cause of stress injuries. It was hypothesized that there would be a reduction in each of the four ankle strength measures that were collected, however only PF and DF were significantly reduced following the ruck march. In a similar study that evaluated the effects of a 21-hour simulated military mission, including a 15km road march while carrying a 43kg ruck, followed by a 1-hour rest and ration period, followed by an intermittent rest and reconnaissance period while carrying a 27kg ruck, before walking back to the laboratory carrying the 43kg ruck. This protocol induced reductions in PF strength that approached significance (10.7%MVC, p=0.06) (Grenier et al., 2012), further supporting that reductions in PF strength may occur during ruck marching. PF and DF strength in runners were also significantly reduced when measuring %MVC of the grastrocnemius and tibialis anterior muscles, as well as the peroneus, and soleus muscles following a prolonged run (Mizrahi et al., 2000; Weist et al., 2004). When investigating the effects of localized DF and INV fatigue on PIF and LR, PF fatigue caused significant increases in LR, while INV fatigue caused significant decreases in peak impact force (Christina et al., 2001). It is possible that greater strength reductions may be observed after a longer ruck march such as the standard Army 12-mile march, however this information is, to the best of the knowledge of the author, currently unknown.

Vertical Jump

In addition to ankle strength, VJ height was collected, however no significant changes were observed from pre-march to post-march, although when considering the inherent mechanical and physiological differences between maximum VJ and a prolonged marching task, this finding is not surprising. These findings do not support the hypothesis that post-march VJ will decrease, nor do they agree with previous studies (Fallowfield et al., 2012; Wang et al., 2012, 2013). It appears as though a ruck march of 4-miles or shorter may not have a significant impact on in lower extremity power, although in ruck marches of greater distances, significant decreases in VJ have been observed (Fallowfield et al., 2012). A possible explanation for this finding is that the musculature used when performing a Queen's College step test is different or used less when walking or marching. During the ascent of a stair climbing activity, which is similar to the Queen's College step test, PF muscular activity peaks during the beginning of the pre-swing phase, after which, DF activity increases to ensure the foot clears the step during the swing phase, but decrease in the second half of the swing phase, and has low levels of activity from initial contact of toe off. The quadriceps group is activated to about 30%MVC at initial contact; increasing to about 60% MVC at the middle of the loading response and decreases as the opposite foot touches down taking over support of the individual. During stair descent, the PF and DF muscles function primarily as stabilizers maintaining activity from just before initial contact and through the stance phase. The quadriceps muscles are less active during stair decent, but still maintain 10-25%MVC throughout the single leg stance phase. During normal walking, PF muscles, particularly the gastroc-soleus muscles are activated to about 80% of MVC during normal walking and are active from loading response to the pre-swing phase which comprises about 50% of the gait cycle. The DF muscles are active at about 40%MVC and are active from the pre-swing phase until the end until of the loading response of gait activating the DF's for over 60% of the gait cycle, whereas the quadriceps group contract to about 30-40%MVC and primarily active only during the initial contact phase of walking which is typically 2% or less of a normal gait cycle (Perry & Burnfield, 2010). One possible explanation for VJ reductions following a 12-mile ruck march, as opposed to the 4-mile ruck march used in the current study, is that more of the lower extremity musculature becomes active as the march progresses continuing to minimize loading of the lower extremities (Fallowfield et al., 2012). It was also thought that post-activation potentiation could have played a role for participants whose VJ increased, however when comparing VJ height to the ruck sack weight relative to participant body weight there was a difference of about 1% between participants who increased their post march VJ when compared to participants whose post march VJ decreased.

HR, RPE and TT

During the ruck march, HR, RPE, and TT data were collected at four lap intervals and again on the final lap to evaluate both physiological and perceived exertion levels of participants. During the march, participants HR climbed from about 75% to about 85% of their age estimated HRmax (figure 3). RPE evaluations also increased throughout the ruck march, from 10.75 to 13.5 with significant increases occurring multiple times, but were below what would be expected when compared with HR taken at the same intervals based on the relationship established by Borg, (1982). HR and RPE have been documented in other military style march studies of varying loads and distances, making any direct comparisons difficult. During a 4-hour road march carrying a 43kg ruck sack, Grenier and colleagues (2012), found that infantrymen had an average HR of 139(±18bpm), and an RPE of 16.7(±2.4) (Grenier et al., 2012; Mullins et al., 2015; R. J. Simpson et al., 2010). Mullins et al., (2015) found that HR increases by about %12, during a 2-hour walk at a 5.5km/h pace carrying a 22kg ruck sack (Mullins et al., 2015), and Simpson et al., (2010) observed a HR of 112, and an RPE of 7.4 while walking at a 6.4 km/h pace while carrying a 20kg ruck sack during the first 3 min. of their experiment which increased required participants to increase their velocity 1km/h every 3min. This study was the first of its kind to utilize the TT as an additional measure of exertion; however, all participants were able to speak clearly throughout the task. As such, no assertions can be made about whether or not participants were working at or above their VT during the ruck march. When considering these three measures, it would appear as though participants perceived the task to be of relatively low intensity as evidenced by their RPE and TT evaluations. HR values however, would suggest that the ruck march was physiologically taxing as indicated by the increase in HR during the ruck march, as well as the decrease that was observed between completion of the march and the collection of post-march measures.

Descriptive Variables

TPSP's including step length, stride length, velocity, and cadence were also collected at 4 lap intervals and again on the final lap to determine if any alterations in gait occurred during the ruck march. Studies that also measured these factors compared differences in TPSP's while manipulating load, velocity, or grade and as such, direct comparisons between these and the current study could not be made (Attwells et al., 2006; Krupenevich et al., 2015; Majumdar et al., 2010). When looking at factors similar to that of the current study, (load, and velocity) TPSP's appeared to be consistent with previous studies, however no significant alterations in gait were observed. TPSP's were also related to changes in PIF when compared across the four participants who displayed the largest and smallest increases in PIF, finding that those with the greater increases in PIF also had longer steps, strides, a greater velocity, and took fewer steps/s, and those with smaller increases in PIF took smaller steps, and strides, and had a slower velocity while taking more steps/s. However, these findings have been well documented in other studies, which is why velocity was controlled for during the collection of force data.

Practical Application

From a mechanical perspective the body had a reduced ability to manage forces following the prolonged ruck march as evidenced by the increases in PIF and LR. The physiological measure of HR was relatively high during the ruck march indicating that the participants were exerting themselves during the task. Psychologically however, participants did not indicate that the task was overly difficult, stating that they perceived their exertion to range from light to somewhat hard as indicated by their RPE. Based on the findings of the current study, it seems possible, if not likely, that multiple bodily systems are interacting while performing a prolonged ruck march, and that they are all likely contributors to the changes that were observed in lower extremity loading.

Clinical Implications

This study improves upon the current body of bone stress injury literature and informs future research on the prevention of military injuries. The significant changes in both peak impact force and LR indicate that even rucking short distances can have a substantial effect on lower extremity loading and, as such, ruck march distances in basic training should be short early on in basic training, gradually increasing the distance as recruits adapt to the training load and are able to complete the task without the presence of localized bony pain.

Limitations

The limitations of this study were that the main outcome measures of peak impact force and LR are not direct measures of bone loading. This study was further limited by the device used to measure ankles strength, tester errors or errors resulting from participants failing to put forth maximal effort could result in some inaccuracies when using a hand-held dynamometer.

Directions for Future Research

The author recommends that future research in this field should attempt to determine what musculature has the greatest shock absorbing effect with regards to lower extremity loading to allow for the development of strength training or muscular endurance programs to help reduce the force reductions within those muscles. The author also recommends that force and loading rate thresholds should be established in order to determine the maximum training load that military personnel can train at without risking bone stress injuries.

Conclusion

Prolonged ruck marching appears to induce significant increases in both PIF and LR, however it remains unclear as to whether or not the magnitude of these injuries is enough to induce stress injuries. The author recommends future research continue to use military style tasks to determine the point during a ruck march at which increases in PIF and LR may become injurious, as well as what muscles might have the greatest effect on changes in PIF and LR. While PIF and LR appeared to be unrelated to PF and DF in the current study there is still substantial evidence that muscular fatigue is a key factor in stress injuries.

References

Arendt, Agel, J., Heikes, & Griffiths. (2003). Stress injuries to bone in college athletes: a retrospective review of experience in a single institution. *American Journal of Sports Medicine, 31*(6), 959-968.

Armstrong, D. W., 3rd, Rue, J. P., Wilckens, J. H., & Frassica, F. J. (2004). Stress fracture injury in young military men and women. *Bone, 35*(3), 806-816. doi:10.1016/j.bone.2004.05.014

Arndt, A., Ekenman, P., Westblad, A., & Lundberg, A. (2002). Effects of fatigue and load variation on metatrsal deformation measured in vivo during barefoot walking. *Journal of Biomechanics, 35*, 621-628.

Attwells, R. L., Birrell, S. A., Hooper, R. H., & Mansfield, N. J. (2006). Influence of carrying heavy loads on soldiers' posture, movements and gait. *Ergonomics, 49*(14), 1527-1537. doi:10.1080/00140130600757237

Barnes, A., Wheat, J., & Milner, C. (2008). Association between foot type and tibial stress injuries: a systematic review. *Br J Sports Med, 42*(2), 93-98. doi:10.1136/bjsm.2007.036533

Bayraktar, H. H., Morgan, E. F., Niebur, G. L., Morris, G. E., Wong, E. K., & Keaveny, T. M. (2004). Comparison of the elastic and yield properties of human femoral trabecular and cortical bone tissue. *Journal of Biomechanics, 37*(1), 27-35. doi:10.1016/s0021-9290(03)00257-4

Bazett-Jones, D. M., Cobb, S. C., Huddleston, W. E., O'Connor, K. M., Armstrong, B. S., & Earl-Boehm, J. E. (2013). Effect of patellofemoral pain on strength and mechanics after an exhaustive run. *Med Sci Sports Exerc, 45*(7), 1331-1339. doi:10.1249/MSS.0b013e3182880019

Beck, Ruff, Shaffer, Betsinger, Trone, & Brodine. (2000). Stress fracture in military recruits: gender differences in muscle and bone sysceptibility factors. *Bone, 27*(3), 437-444.

Beck, T. J., Ruff, C. B., Mourtada, F. A., Shaffer, R. A., Maxwell-Williams, K., Kao, G. L., . . . Brodine, S. (1996). Dual-energy X-ray absorptiometry derived structural geometry for stress fracture prediction in male U.S. Marine Corps recruits. *J Bone Miner Res, 11*(5), 645-653. doi:10.1002/jbmr.5650110512

Bennell, K., Crossley, K., Jayarajan, J., Walton, E., Warden, S., Kiss, Z. S., & Wrigley, T. (2004). Ground reaction forces and bone parameters in females with tibial stress fracture. *Med Sci Sports Exerc, 36*(3), 397-404.

Bigland-Ritchie, B. (1981). EMG/force relations and fatigue of human voluntary contractions. *Exercise and Sport Sciences Reviews, 9*, 75-113.

Birrell, S. A., & Haslam, R. A. (2009). The effect of military load carriage on 3-D lower limb kinematics and spatiotemporal parameters. *Ergonomics, 52*(10), 1298-1304. doi:10.1080/00140130903003115

Birrell, S. A., Hooper, R. H., & Haslam, R. A. (2007). The effect of military load carriage on ground reaction forces. *Gait Posture, 26*(4), 611-614. doi:10.1016/j.gaitpost.2006.12.008

Bohannon, R. W. (1986). Test-retest reliability of hand-held dynamometry during a single session of stregnth assessment. *Journal of the American Physical Therapy Association, 66*, 206-209.

Borg, G. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise, 14*(5), 377-381.

Brunet, M. E., Cook, S. D., Brinker, M. R., & Dickinson, J. A. (1990). A survey of running injuires in 1505 competitive and recreational runners. *THe Journal of sports of medicine and physical fitness, 30*(3).

Burr, D. B. (2002). Targeted and Nontargeted Remodeling. *Bone, 30*(1), 2-4.

Changstrom, B. G., Brou, L., Khodaee, M., Braund, C., & Comstock, R. D. (2015). Epidemiology of stress fracture injuries among US high school athletes, 2005-2006 through 2012-2013. *Am J Sports Med, 43*(1), 26-33. doi:10.1177/0363546514562739

Chatzipapas, C. N., Drosos, G. I., Kazakos, K. I., Tripsianis, G., Iatrou, C., & Verettas, D. A. (2008). Stress fractures in military men and bone quality related factors. *Int J Sports Med, 29*(11), 922-926. doi:10.1055/s-2008-1038690

Cheung, R. T., & Rainbow, M. J. (2014). Landing pattern and vertical loading rates during first attempt of barefoot running in habitual shod runners. *Hum Mov Sci, 34*, 120-127. doi:10.1016/j.humov.2014.01.006

Christina, K. A., White, S. C., & Gilchrist, L. A. (2001). Effect of localized muscle fatigue on vertical ground reaction forces and ankle joint motion during running. *Human Movement Science, 20*, 257-276.

Claasen, Hu, & Rohrbeck. (2014). Fractures among active component, recruit trainees, and deployed service members, U.S. armed forces, 2003-2012. *MSMR, 21*(9), 1-7.

Clansey, A. C., Hanlon, M., Wallace, E. S., & Lake, M. J. (2012). Effects of fatigue on running mechanics associated with tibial stress fracture risk. *Med Sci Sports Exerc, 44*(10), 1917-1923. doi:10.1249/MSS.0b013e318259480d

Cosman, F., Ruffing, J., Zion, M., Uhorchak, J., Ralston, S., Tendy, S., . . . Nieves, J. (2013). Determinants of stress fracture risk in United States Military Academy cadets. *Bone, 55*(2), 359-366. doi:10.1016/j.bone.2013.04.011

Daffner, R. H., & Pavlov, H. (1992). Stress fractures: current concepts. *AJR, 159*, 245-252.

Davis, I., Milner, C. E., & Hamill, J. (2004). Does Increased loading during running lead to tibial stress fracture? A prospective study. *Medicine & Science in Sports & Exercise, 36*(5).

Divert, C., Mornieux, G., Freychat, P., Baly, L., Mayer, F., & Belli, A. (2008). Barefoot-shod running differences: shoe or mass effect? *Int J Sports Med, 29*(6), 512-518. doi:10.1055/s-2007-989233

Ekenman, Milgron, Finestone, Begin, Olin, Arndt, & Burr. (2002). The role of biomechanics shoe orthoses in tibial stress fracture prevention. *The American Journal of Sports Medicine, 30*(6), 866-870.

Evans, R. K., Negus, C., Antczak, A. J., Yanovich, R., Israeli, E., & Moran, D. S. (2008). Sex differences in parameters of bone strength in new recruits: beyond bone density. *Med Sci Sports Exerc, 40*(11 Suppl), S645-653. doi:10.1249/MSS.0b013e3181893cb7

Fallowfield, J. L., Blacker, S. D., Willems, M. E., Davey, T., & Layden, J. (2012). Neuromuscular and cardiovascular responses of Royal Marine recruits to load carriage in the field. *Appl Ergon, 43*(6), 1131-1137. doi:10.1016/j.apergo.2012.04.003

Farr, J. N., Chen, Z., Lisse, J. R., Lohman, T. G., & Going, S. B. (2010). Relationship of total body fat mass to weight-bearing bone volumetric density, geometry, and strength in young girls. *Bone, 46*(4), 977-984. doi:10.1016/j.bone.2009.12.033

Franklyn, M., Oakes, B., Field, B., Wells, P., & Morgan, D. (2008). Section modulus is the optimum geometric predictor for stress fractures and medial tibial stress syndrome in both male and female athletes. *Am J Sports Med, 36*(6), 1179-1189. doi:10.1177/0363546508314408

Fredericson, M., Bergman, A. G., Hoffman, K. L., & Dillingham, M. S. (1995). Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. *Am J Sports Med, 23*(4), 472-481.

Fyhrie, D. P., Milgrom, C., Hoshaw, S. J., Simkin, A., Dar, S., Drumb, D., & Burr, D. B. (1998). Effect of fatiguing exercise on longitudinal bone strain as related to stress fracture in humans. *Annals of Biomedical Engineering, 26*, 660-665.

Gaffney-Stomberg, E., Lutz, L. J., Rood, J. C., Cable, S. J., Pasiakos, S. M., Young, A. J., & McClung, J. P. (2014). Calcium and vitamin D supplementation maintains parathyroid hormone and improves bone density during initial military training: a randomized, double-blind, placebo controlled trial. *Bone, 68*, 46-56. doi:10.1016/j.bone.2014.08.002

Gandevia, S. C. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiology Reviews, 81*(4), 1725-1789.

Gardner, Dziados, Jones, & Brundage. (1988). Prevention of lower extremity stress fractures: a controlled trial of shock absorbent insole. *American Journal of Public Health, 78*(12), 1563-1567.

Gefen, A. (2002). Biomechanical analysis of fatigue-related foot injury mechanisms in athletes and recruits during intensive marching. *Medical & Biological engineering & computing, 40*(302-10).

Giandolini, M., Arnal, P. J., Millet, G. Y., Peyrot, N., Samozino, P., Dubois, B., & Morin, J. B. (2013). Impact reduction during running: efficiency of simple acute interventions in recreational runners. *Eur J Appl Physiol, 113*(3), 599-609. doi:10.1007/s00421-012-2465-y

Giladi, M., Milgrom, C., Simkin, A., & Danon, Y. (1991). Stress fractures: identifiable risk fractors. *The American Journal of Sports Medicine, 19*(6), 647-652.

Grenier, J. G., Millet, G. Y., Peyrot, N., Samozino, P., Oullion, R., Messonnier, L., & Morin, J. B. (2012). Effects of extreme-duration heavy load carriage on neuromuscular function and locomotion: a military-based study. *PLoS One, 7*(8), e43586. doi:10.1371/journal.pone.0043586

Groves, A. M., Cheow, H. K., Balan, K. K., Bearcroft, P. W., & Dixon, A. K. (2005). 16 detector multislice CT versus skeletal scintigraphy in the diagnosis of wrist fractures: value of quantification of Tc-MDP uptake. *The British Journal of Radiology, 78*, 791-795.

Harrast, M. A., & Colonno, D. (2010). Stress fractures in runners. *Clin Sports Med, 29*(3), 399-416. doi:10.1016/j.csm.2010.03.001

Hauret, K. G., Jones, B. H., Bullock, S. H., Canham-Chervak, M., & Canada, S. (2010). Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med, 38*(1 Suppl), S61-70. doi:10.1016/j.amepre.2009.10.021

Haverstock, B. D. (2001). Stress fractures of the foot and Ankle. *Clinics in podiatric medicine and surgery, 18*(2), 273-284.

House, C., Reece, A., & Roiz de Sa, D. (2013). Shock-absorbing insoles reduce the incidence of lower limb overuse injuries sustained during Royal Marine training. *Mil Med, 178*(6), 683-689. doi:10.7205/MILMED-D-12-00361

Iwamoto, & Takeda. (2003). Stress fractures in athletes: review of 196 cases. *Journal of Orthopaedic Science, 8*(3), 273-278.

James, C. R., Dufek, J. S., & Bates, B. T. (2006). Effects of stretch shortening cycle exercise fatigue on stresss fracture injury risk during landing. *Research quarterly for exercise and sport, 77*(1), 1-13.

Knapik, J., Montain, S. J., McGraw, S., Grier, T., Ely, M., & Jones, B. H. (2012). Stress fracture risk factors in basic combat training. *Int J Sports Med, 33*(11), 940-946. doi:10.1055/s-0032-1311583

Knapik, J. J., Reynolds, K. L., & Harman, E. (2004). Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Military Medicine, 169*(1), 45-56.

Korpelainen, R., Orava, S., Karapakka, J., Siira, P., & Hulkko, A. (2001). Risk factors for recurrent stress fractures in athletes. *The American Journal of Sports Medicine, 29*(3), 304-310.

Krupenevich, R., Rider, P., Domire, Z., & DeVita, P. (2015). Males and Females Respond Similarly to Walking With a Standardized, Heavy Load. *Mil Med, 180*(9), 994-1000. doi:10.7205/milmed-d-14-00499

Kupferer, K. R., Bush, D. M., Cornell, J. E., Lawrence, V. A., Alexander, J. L., Ramos, R. G., & Curtis, D. (2014). Femoral neck stress fracture in Air Force basic trainees. *Mil Med, 179*(1), 56-61. doi:10.7205/milmed-d-13-00154

Lappe, J. M., Stegman, M. R., & Recker, R. R. (2001). The impact of lifestyle factors on stress fractures in female army recruits. *Osteoporosis International, 12*, 35-42.

Lee. (2011). Stress fractures, active component, U.S. armed forces, 2004-2010. *MSMR, 18*(05), 8-11.

Lee, C. D. (2011). Stress fractures, active component, U.S. armed forces, 2004-2010. *18*(5), 8-11.

Lee, S., & Anderson, R. B. (2004). Stress fractures of the tarsal navicular. *Foot and Ankle Clinics, 9*(1), 85-104. doi:10.1016/s1083-7515(03)00151-7

Lyon, E., Menke, M., Foster, C., Porcari, J. P., Gibson, M., & Bubbers, T. (2014). Translation of incremental talk test responses to steady-state exercise training intensity. *J Cardiopulm Rehabil Prev, 34*(4), 271-275. doi:10.1097/hcr.0000000000000069

Macera, Powell, Jackson, Kendrick, & Craven. (1989). Predicting lower-extremity injuries among habitual runners. *Archives of Internal Medicine, 149*(11), 2565-2568.

Majumdar, D., Pal, M. S., & Majumdar, D. (2010). Effects of military load carriage on kinematics of gait. *Ergonomics, 53*(6), 782-791. doi:10.1080/00140131003672015

Majumdar, D., Pal, M. S., Pramanik, A., & Majumdar, D. (2013). Kinetic changes in gait during low magnitude military load carriage. *Ergonomics, 56*(12), 1917-1927. doi:10.1080/00140139.2013.835871

Mattila, V. M., Niva, M., Kiuru, M., & Pihlajamaki, H. (2007). Risk factors for bone stress injuries: a follow-up study of 102,515 person-years. *Med Sci Sports Exerc, 39*(7), 1061-1066. doi:10.1249/01.mss.0b013e318053721d

McCabe, M. P., Smyth, M. P., & Richardson, D. R. (2012). Current concept review: vitamin D and stress fractures. *Foot Ankle Int, 33*(6), 526-533. doi:10.3113/fai.2012.0526

Mentiplay, B. F., Perraton, L. G., Bower, K. J., Adair, B., Pua, Y. H., Williams, G. P., . . . Clark, R. A. (2015). Assessment of Lower Limb Muscle Strength and Power Using Hand-Held and Fixed Dynamometry: A Reliability and Validity Study. *PLoS One, 10*(10), e0140822. doi:10.1371/journal.pone.0140822

Milgrom, Giladi, Chisin, & Dizian. (1985). The long-term followup of soldiers with stress fractures. *The American Journal of Sports Medicine, 13*(6), 398-400.

Milgrom, C., Finestone, A., Segev, S., Olin, C., Arndt, T., & Ekenman, I. (2003). Are overground or treadmill runners more likely to sustain tibial stress fracture? *British Journal of Sports Medicine, 37*(2), 160-163.

Milgrom, C., Radeva-Petrova, D. R., Finestone, A., Nyska, M., Mendelson, S., Benjuya, N., . . . Burr, D. (2007). The effect of muscle fatigue on in vivo tibial strains. *J Biomech, 40*(4), 845-850. doi:10.1016/j.jbiomech.2006.03.006

Miller, J. R., Dunn, K. W., Ciliberti, L. J., Jr., Patel, R. D., & Swanson, B. A. (2016). Association of Vitamin D With Stress Fractures: A Retrospective Cohort Study. *J Foot Ankle Surg, 55*(1), 117-120. doi:10.1053/j.jfas.2015.08.002

Milner, C. E., Ferber, R., Pollard, C. D., Hamill, J., & Davis, I. S. (2006). Biomechanical factors associated with tibial stress fracture in female runners. *Med Sci Sports Exerc, 38*(2), 323-328. doi:10.1249/01.mss.0000183477.75808.92

Mizrahi, J., Verbitsky, O., & Isakov, E. (2000). Fatigue-related loading imbalance on the shank in running: a possible factor in stress fractures. *Annals of Biomedical Engineering, 28*(4), 463-469.

Mullins, A. K., Annett, L. E., Drain, J. R., Kemp, J. G., Clark, R. A., & Whyte, D. G. (2015). Lower limb kinematics and physiological responses to prolonged load carriage in untrained individuals. *Ergonomics, 58*(5), 770-780. doi:10.1080/00140139.2014.984775

Myburgh, K. H., Hutchins, J., Fataar, A. B., Hough, S. F., & Noakes, T. D. (1990). Low bone density is a etiologic factor for stress fractures in athletes. *Annals of Internal Medicine, 113*, 754-759.

Nieves, J. W., Melsop, K., Curtis, M., Kelsey, J. L., Bachrach, L. K., Greendale, G., . . . Sainani, K. L. (2010). Nutritional factors that influence change in bone density and stress fracture risk among young female cross-country runners. *Pm r, 2*(8), 740-750; quiz 794. doi:10.1016/j.pmrj.2010.04.020

Niva, M. H., Sormaala, M. J., Kiuru, M. J., Haataja, R., Ahovuo, J. A., & Pihlajamaki, H. K. (2007). Bone stress injuries of the ankle and foot: an 86-month magnetic resonance imaging-based study of physically active young adults. *Am J Sports Med, 35*(4), 643-649. doi:10.1177/0363546506295701

Noakes, T. D., St Clair Gibson, A., & Lambert, E. V. (2005). From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans: summary and conclusions. *Br J Sports Med, 39*(2), 120-124. doi:10.1136/bjsm.2003.010330

Plotkin, L. I. (2014). Apoptotic osteocytes and the control of targeted bone resorption. *Curr Osteoporos Rep, 12*(1), 121-126. doi:10.1007/s11914-014-0194-3

Pohl, M. B., Mullineaux, D. R., Milner, C. E., Hamill, J., & Davis, I. S. (2008). Biomechanical predictors of retrospective tibial stress fractures in runners. *J Biomech, 41*(6), 1160-1165. doi:10.1016/j.jbiomech.2008.02.001

Popp, K. L., Hughes, J. M., Smock, A. J., Novotny, S. A., Stovitz, S. D., Koehler, S. M., & Petit, M. A. (2009). Bone geometry, strength, and muscle size in runners with a history of stress fracture. *Med Sci Sports Exerc, 41*(12), 2145-2150. doi:10.1249/MSS.0b013e3181a9e772

Potter, Gardner, Deuster, Jenkins, Mckee, & Jones. (2002). Musculoskeletal injureis in an army airborne population. *Military Medicine, 167*(12), 1033-1040.

Quesada, P. M., Mengelkoch, L. J., Hale, R. C., & Simon, S. R. (2000). Biomechanical and metabolic effects of varying backpack loading on simulated marching. *Ergonomics, 43*(3), 293-309. doi:10.1080/001401300184413

Rittweger, J., Beller, G., Ehrig, J., Jung, C., Koch, U., Ramolla, J., . . . Felsenberg, D. (2000). Bone-muscle strength indices for the human lower leg. *Bone, 27*(2), 319-326.

Rudzki, S. J. (1997). Injuries in Australian Army recruits: Part 1: decreased incidence and severity of injury seen with reduced running distance. *Military Medicine, 162*(7), 472-476.

Salzler, M. J., Bluman, E. M., Noonan, S., Chiodo, C. P., & de Asla, R. J. (2012). Injuries observed in minimalist runners. *Foot Ankle Int, 33*(4), 262-266. doi:10.3113/FAI.2012.0262

Seay, J. F. (2015). Biomechanics of load carraige - Historical perspectives and recent insights. *Journal of Strength and Conditioning Research, 29*, S129-S133.

Shaffer, A. R., Rauh, M. J., Brodine, S. K., Trone, D. W., & Macera, C. A. (2006). Predictors of stress fracture suceptiblity in young female recruits. *The American Journal of Sports Medicine, 34*(1), 108-115.

Simpson, K. M., Munro, B. J., & Steele, J. R. (2012). Effects of prolonged load carriage on ground reaction forces, lower limb kinematics and spatio-temporal parameters in female recreational hikers. *Ergonomics, 55*(3), 316-326. doi:10.1080/00140139.2011.642004

Simpson, R. J., Graham, S. M., Florida-James, G. D., Connaboy, C., Clement, R., & Jackson, A. S. (2010). Perceived exertion and heart rate models for estimating metabolic workload in elite British soldiers performing a backpack load-carriage task. *Appl Physiol Nutr Metab, 35*(5), 650-656. doi:10.1139/h10-053

Snoddy, R. O., Jr., & Henderson, J. M. (1994). Predictors of basic infantry training success. *Mil Med, 159*(9), 616-622.

Sonneville, K. R., Gordon, C. M., Kocher, M. S., Pierce, L. M., Ramappa, A., & Field, A. E. (2012). Vitamin d, calcium, and dairy intakes and stress fractures among female adolescents. *Arch Pediatr Adolesc Med, 166*(7), 595-600. doi:10.1001/archpediatrics.2012.5

Thomas, D. Q., Lumpp, S. A., Schreiber, J. A., & Keith, J. A. (2004). Physical fitness profile of army ROTC cadets. *Journal of Strength and Conditioning Research, 18*(4), 904-907.

Thompson, M. A., Gutmann, A., Seegmiller, J., & McGowan, C. P. (2014). The effect of stride length on the dynamics of barefoot and shod running. *J Biomech, 47*(11), 2745-2750. doi:10.1016/j.jbiomech.2014.04.043

Trone, Reis, Macera, & Rauh. (2007). Factors assocaited with discharge during marine corps basic training. *Military Medicine, 172*(9), 936-941.

Valimaki, V. V., Alfthan, H., Lehmuskallio, E., Loyttyniemi, E., Sahi, T., Suominen, H., & Valimaki, M. J. (2005). Risk factors for clinical stress fractures in male military recruits: a prospective cohort study. *Bone, 37*(2), 267-273. doi:10.1016/j.bone.2005.04.016

Verbitsky, O., Mizrahi, J., Voloshin, A., Treiger, J., & Isakov, E. (1998). Shock transmission and fatigue in human running. *Journal of Applied Biomechanics, 14*, 300-311.

Voloshin, A. S., Mizrahi, J., Verbitsky, O., & Isakov, E. (1998). Dynamic loading on the human musculoskeletal system —effect of fatigue. *Clinical Biomechanics, 13*(7), 515-520. doi:10.1016/s0268-0033(98)00030-8

Walter, S. D., Hart, L. E., McIntosh, J. M., & Sutton, J. R. (1989). The ontario corhort study of running-related injuries. *Archives of Internal Medicine, 149*(11), 2561-2564.

Wang, H., Frame, J., Ozimek, E., Leib, D., & Dugan, E. L. (2012). Influence of fatigue and load carriage on mechanical loading during walking. *Military Medicine, 177*(2), 152-156.

Wang, H., Frame, J., Ozimek, E., Leib, D., & Dugan, E. L. (2013). The effects of load carriage and muscle fatigue on lower-extremity joint mechanics. *Research quarterly for exercise and sport, 84*(3), 305-312. doi:10.1080/02701367.2013.814097

Warden, Burr, & Brunker. (2006). Stress fractures: phathophysiology, epidemiology, and risk factors. *Current Osteoporosis reports, 4*(3), 103-109.

Warden, S. J., Davis, I. S., & Fredericson, M. (2014). Management and prevention of bone stress injuries in long-distance runners. *J Orthop Sports Phys Ther, 44*(10), 749-765. doi:10.2519/jospt.2014.5334

Weir, J. P., Beck, T. W., Cramer, J. T., & Housh, T. J. (2006). Is fatigue all in your head? A critical review of the central governor model. *Br J Sports Med, 40*(7), 573-586; discussion 586. doi:10.1136/bjsm.2005.023028

Weist, R., Eils, E., Rosenbaum, D., & Doz, P. (2004). The Influence of Muscle Fatigue on Electromyogram and Plantar Pressure Patterns as an Explanation for the Incidence of Metatarsal Stress Fractures. *American Journal of Sports Medicine, 32*(8), 1893-1898. doi:10.1177/0363546504265191

Yoshikawa, T., Mori, S., Santiesteban, A. J., Sun, T. C., Hafstad, E., Chen, J., & Burr, D. B. (1994). The effects of muscle fatigue on bone strain. *1994, 188*(217-33).

APPENDIX A: CONSENT DOCUMENT

UNIVERSITY OF WISCONSIN – MILWAUKEE
CONSENT TO PARTICIPATE IN RESEARCH

THIS CONSENT FORM HAS BEEN APPROVED BY THE IRB FOR A ONE YEAR PERIOD

1. General Information

Study Title:
The effects of military style marching on lower extremity loading.

Person in Charge of Study (Principal Investigator):
The Principal Investigator (PI) for this study is Jennifer Earl-Boehm, Ph.D., LAT. Dr. Earl-Boehm is a faculty member in the Department of Kinesiology and is the Director of the Athletic Training Education Program. The Co-PI on this study is Daniel Poel.

2. Study Description

You are being asked to participate in a research study. Your participation is completely voluntary. You do not have to participate if you do not want to.

Study description:
The purpose of this study is determine the forces being applied to the body after performing a ruck march.

This study is being done to determine the effects ruck marching might have on the human body, allowing for a greater understanding of ruck marching and to offer insight as to why ruck marching injuries might occur.

The study will take place in the Neuromechanics Laboratory (Enderis 132) at the University of Wisconsin-Milwaukee, and in the University of Wisconsin-Milwaukee Klotsche center gymnasium. Approximately 23 subjects will participate in this study.

3. Study Procedures

What will I be asked to do if I participate in the study?
If you agree to participate you will be asked to report to the Neuromechanics Laboratory (Enderis 132) at the University of Wisconsin-Milwaukee for session.

Part 1 (~30 minutes)

- You will need to wear your military uniform (fatigues) and boots, and bring your helmet and vest.
- You will be asked several questions about your medical history, history of injury to the lower extremity, and about your physical activity.
- Your name and preferred email will be recorded into the participant key and will be linked to your unique participant ID code under which all of your data will be saved.
- Someone will ask your age and measure your height and weight
- A researcher will contact the ROTC office to obtain your most recent Army Physical Fitness Test score, if you are regular Army you will be asked to provide these scores yourself.
- You will put on a heart rate monitor that is a strap that you will wear around your chest under your shirt. There is a private place to change and put on the monitor. You will also be given a watch to wear during testing to measure your heart rate.
- You will lie down on a padded bed for 5 minutes while we measure your resting heart rate
- You will perform a 5 min. warm-up consisting of treadmill walking at a brisk self-selected pace
- You will complete 3 maximum vertical jumps
- The ankle strength on your dominant leg will be tested
    - 3 measures will be collected in each of four movements
-

Part 2 (~90 minutes)

- Next you will put on your complete military uniform including helmet, vest, and a 16kg ruck sack that will be provided for you.
    - You will walk across the room at a brisk pace (1.79m/s) and step on a force plate. You can practice this several times until you feel comfortable and your foot hits the force plate.
    - 5 more walking trials will be done
- You will then be escorted by a research assistant and walk outside to the Klotsche Center (~200 m). You will complete a 4 mile ruck march around the indoor track of the Klotsche center. You can select your preferred walking pace, but you must walk (not run) and complete the 4 miles in under 60 minutes.
- Without stopping at all, you will walk back to the lab in Enderis and immediately perform 5 more walking trials following the same procedure as above
- You will then perform 3 more maximum vertical jump tests without your helmet vest or ruck sack
- Your ankle strength will be measured again following the same protocol as above

4. Risks and Minimizing Risks

What risks will I face by participating in this study?

Physical Risks

- Muscle soreness as a result of testing (unlikely)

- Musculoskeletal injuries such as muscle strain as a result of testing (unlikely)
- Musculoskeletal injuries to the foot, ankle, shin, knee, thigh, or hip as a result of the ruck march (unlikely)

Protection of Physical Risks

- The inclusion and exclusion criteria were established to help decrease the risk of these injuries
- To reduce the above risks, you will be allowed to practice all tests prior to data collection until you feel comfortable with the task. If you feel any soreness or strain while participating in this study, please tell the investigators as soon as possible. You will be provided initial care by investigators, who are all certified in first aid and CPR, and will then be referred to the Norris Health Center (student) for follow-up care for follow-up care.

Psychological or Social Risks

- None

Risk to Privacy and Confidentiality:

- Since your private information will be collected for this study, there is always a risk of breach of confidentiality (less than 1%).

Protection of Risk to Privacy and Confidentiality

- All data will be stored in a locked filing cabinet in a locked room. All data will be given a letter and number that is uniquely associated with you. This code will not contain any partial identifiers (i.e. last four digits of your SSN) and will be stored in a separate locked office in a locked filing cabinet. No identifiers will be stored with the research data. Only those individuals with an active role in this study will have access to the research data and only the PI and Co-PI will have access to identifying information. When all participants complete active participation in the study and data collection is completed, the code will be destroyed. All appropriate measures to protect your private information will be taken.

5. Benefits

Will I receive any benefit from my participation in this study?
It is unlikely that you will directly benefit from participation in this study, however the information obtained in this study may benefit future ROTC cadets and military personnel.

6. Study Costs and Compensation

Will I be charged anything for participating in this study?
You will not be responsible for any of the costs from taking part in this research study.

Are subjects paid or given anything for being in the study?
You will receive a $50 gift card following the completion of testing.

7. Confidentiality

What happens to the information collected?
All information collected about you during the course of this study will be kept confidential to the extent permitted by law. We may decide to present what we find to others, or publish our results in scientific journals or at scientific conferences. Information that identifies you personally will not be released without your written permission. Only the PI and the Co-PI will have access to the information. However, the Institutional Review Board at UW-Milwaukee or appropriate federal agencies like the Office for Human Research Protections may review this study's records.

All information will be coded and stored in a locked file cabinet. The participant key that links the identifiable data (participant's name and email) and the participant code will be stored separately and will be destroyed when the study is complete.

8. Alternatives

Are there alternatives to participating in the study?
There are no alternatives available to you other than not taking part in this study.

9. Voluntary Participation and Withdrawal

What happens if I decide not to be in this study?
Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee. If you chose to withdraw, we will use the information collected to that point. If you are students, your refusal to take part in the study will not affect your grade or class standing.

10. Questions

Who do I contact for questions about this study?
For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Jennifer Earl-Boehm, Ph.D, LAT
Department of Kinesiology
PO Box 413, Milwaukee, WI 53201
414-229-3227

Who do I contact for questions about my rights or complaints towards my treatment as a research subject?
The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board
Human Research Protection Program
Department of University Safety and Assurances
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201
(414) 229-3173

11. Signatures

Research Subject's Consent to Participate in Research:
To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.

____
Printed Name of Subject/ Legally Authorized Representative

____ ____________________
Signature of Subject/Legally Authorized Representative Date

Principal Investigator (or Designee)
I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.

____ ____________________
Printed Name of Person Obtaining Consent Study Role

Signature of Person Obtaining Consent Date

APPENDIX B: BACKGROUND INFORMATION QUESTIONNAIRE

Background Information Questionnaire

Screening Criteria

Please answer the following questions to the best of your ability:

☐ Yes ☐ No Are you at least 18 years old?

☐ Yes ☐ No Are you currently medically cleared to participate in all physical training?

Medical History

READ BY INVESTIGATOR: "To better understand the changes that may occur after the prolonged ruck-march I would like to ask you several questions about your medical history and physical training. All of these questions have been chosen because we know that these factors can be related to bone health or physical fitness."

☐ Yes ☐ No Have you ever had a lower extremity injury that caused you to decrease the amount of physical activity you undertake?

☐ Yes ☐ No Bone stress injuries (shin splints, stress fracture)

If yes, approximately how many injuries? ________________________

If yes, in what part of your body?________________________________

If yes, when did this occur?__________________________________

☐ Yes ☐ No Hip injury(ies)

If yes, approximately how many injuries?________________________

If yes, when did this occur?__________________________________

☐ Yes ☐ No Knee injury(ies)

If yes, approximately how many injuries? ________________________

If yes, when did this occur?__________________________________

☐ Yes ☐ No Ankle/foot injury(ies)

If yes, approximately how many injuries? ________________________

If yes, when did this occur?__________________________________

☐ Yes ☐ No Have you had, in the last 6 months, a lower extremity injury that caused you to decrease the amount of physical activity you undertake?

☐ Yes ☐ No Do you currently have any lower extremity pain or injury(ies)?

☐ Yes ☐ No Do you regularly use/wear foot orthotics or shoe inserts?

☐ Yes ☐ No Are you currently taking any medications or supplements?
If yes, list
them____

☐ Yes ☐ No Do you participate in any additional ROTC/military physical training/events/competitions (other than what is required)?
If yes, please describe___________________________

☐ Yes ☐ No Do you participate in any additional physical activities/exercise outside of ROTC?
If yes, please describe____________________________

What is the brand of military boot that you wear?____

How many years have you participated in the ROTC/military?_________________________________

Have you completed Army Basic Training?_____________________________

Comments/Notes: ____
____
____
____

APPENDIX C: RATE OF PERCEIEVED EXERTION 6-20 BORG SCALE

RPE 6-20 Borg Scale		
No Exertion	6	Little to know movement, relaxed
Extremely light	7	
	8	
Very light	9	Comfortable, breathing harder
	10	
Light	11	Light sweating, otherwise unaffected
	12	
Somewhat Hard	13	Beginning to breath heavy, starting to feel the burn
	14	Increased sweating
Hard	15	Sweating, able to keep marching and maintain form
	16	
Very Hard	17	Beginning to feel winded but able to continue
	18	
Extremely Hard	19	Difficult to breath, can't go much longer
Maximally Hard	20	Can't march any longer

APPENDIX D: DATA COLLECTION PROTOCAL

Data Collection Protocol

Before Participant Arrival

Print forms	

Set up equipment
Lab
• **Equipment:**
  ○ **HHD**
    ▪ **Set-up table**
  ○ **Force plate**
  ○ **Timing gate (7.4m between gates)**
Gymnasium
• **Equipment:**
  ○ **Gait mat**
  ○ **HR monitor**
  ○ **RPE scale**
  ○ **Stop watch**
  ○ **Ruck Sack**
  Water	

Force Plate Calibration	

After Participant Arrival

PRE-MARCH	
Initial screening form • **Read to participant**	
Consent form • **Give to participant** • **Keep signature page** **Participant keeps packet**	
Data collection form • **Measure height** **Measure weight (w/o gear)**	

DATA COLLECTION	
DP reads questions from Background Information Form to the participant.	
Establish resting HR • HR monitor strap will be worn across the breast bone just below the nipple line • Calculate HRmax (220-age)	
PRE-MARCH	**INSTRUCTIONS**
Ankle Strength Measures • Inversion • Eversion • Dorsiflexion • Plantarflexion	• Remove the boot and sock from your dominant foot • Lie supine • Apply maximal forces for 5 sec. • Allow 10-30 sec. rest between trials Inversion: Place HHD on the medial foot over the first metatarsal head Eversion: Place HHD on the later foot over the fifth metatarsal head Dorsiflexion: Place HHD on top of the foot on metatarsal heads Plantarflexion: Place HHD on the bottom of the foot on metatarsal heads

Vertical Jump
• LabView
• 5 min. jog on treadmill for warm up
• Allow 2-4 practice trials
• Perform w/o ruck, helmet, vest
	LabView set up
	• Start menu
	  ○ LabView
	    ▪ GRF-Jumping tab
	      • Click Run ⍰
	        ○ Collect BW
	        ○ Click “Play” button Instruct participant to jump
	        ○ Subtract BW
	        ○ Calc Impulse
	          ▪ Record jump height and power
	Vertical Jump
	• Simultaneously squat and throw your arms back
	• Spend as little time in the squat as possible
	• Simultaneously throw your arms up and explode upward

<table>
<tr><td></td><td>(demonstrate if possible)</td></tr>
<tr><td>Peak Impact Force
Establish total weight w/
Ruck sack
Helmet
Vest
Complete 5 walking trials
Entire foot (dominant) must strike force plate
Walk at 1.79m/s (±0.25)
No alterations in gait
Must be completed in 3.88-4.38sec.</td>
<td>Weight
Stand as still as you can
Walking
While walking, strike the force plate in stride with your dominant foot
(foot you kick a ball with)
Do not adjust your stride so that you hit the force plate</td></tr>
<tr><td>Explain
RPE
Talk Test</td>
<td><table>
<tr><th colspan="3">RPE 6-20 Borg Scale</th></tr>
<tr><td>No Exertion</td><td>6</td><td>Little to know movement, relaxed</td></tr>
<tr><td>Extremely light</td><td>7</td><td></td></tr>
<tr><td></td><td>8</td><td></td></tr>
<tr><td>Very light</td><td>9</td><td>Comfortable, breathing harder</td></tr>
<tr><td></td><td>10</td><td></td></tr>
<tr><td>Light</td><td>11</td><td>Light sweating, otherwise unaffected</td></tr>
<tr><td></td><td>12</td><td></td></tr>
<tr><td>Somewhat Hard</td><td>13</td><td>Beginning to breath heavy, starting to feel the burn</td></tr>
<tr><td></td><td>14</td><td>Increased sweating</td></tr>
<tr><td>Hard</td><td>15</td><td>Sweating, able to keep marching and maintain form</td></tr>
<tr><td></td><td>16</td><td></td></tr>
</table></td></tr>
</table>

	<table><tr><td>Very Hard</td><td>17</td><td>Beginning to feel winded but able to continue</td></tr><tr><td></td><td>18</td><td></td></tr><tr><td>Extremely Hard</td><td>19</td><td>Difficult to breath, can't go much longer</td></tr><tr><td>Maximally Hard</td><td>20</td><td>Can't march anymore</td></tr></table> **Talk Test** • Every ½ mile you will be asked to recite the "Pledge of Allegiance" • You will be asked if you can speak clearly • Answer YES, YES BUT…, or NO **(Tester)** • for and answer of yes circle "YES" • For an answer of yes but… circle "EQ" • For the last yes answer before EQ circle "LP" • For an answer of no, or if they are unable to speak, circle "NEG"
RUCK MARCH	**INSTRUCTIONS**
• Record every ½ mile (4 laps) ○ HR ○ RPE ○ Talk test ○ Time • Transfer from GAITRite every ½ mile (4 laps) ○ Step Length ○ Cadence ○ Velocity Proceed immediately to lab w/o slowing or removing any gear.	• You will have 60min. to complete this 4 mile ruck march. • You may choose your own pace • Do NOT run Every half mile you will: • Recite the pledge of allegiance ○ State whether you can speak comfortably (yes, kind of, no) • Allow me to record your HR • Estimate your level of exertion as best you can Upon completion proceed immediately to the lab
POST MARCH	**VERBAL INSTUCTIONS**
Complete 5 walking trials • Entire foot (dominant)	Walking • While walking, strike the force plate in stride with your dominant foot ○ (foot you kick a ball with)

• must strike force plate • Walk at 1.79m/s (±0.25) • No alterations in gait Must be completed in 3.88-4.38sec.	• Do not adjust your stride so that you hit the force plate
Vertical Jump height (3 trials) • 2-4 practice trials • performed w/o ruck, helmet, vest	• Simultaneously squat and throw your arms back • Spend as little time in the squat as possible • Simultaneously throw your arms up and explode upward (demonstrate if possible)
Ankle Strength (3 trials each) • Inversion • Eversion • Dorsiflexion • Plantarflexion	• Remove the boot and sock from your dominant foot • Lie supine • Apply maximal forces for 5 sec. Inversion: Place HHD on the medial foot over the first metatarsal head Eversion: Place HHD on the later foot over the fifth metatarsal head Dorsiflexion: Place HHD on top of the foot on metatarsal heads Plantarflexion: Place HHD on the bottom of the foot on metatarsal heads

APPENDIX E: DATA LOG SHEET

UWM RUCK MARCHING STUDY DATA LOG SHEET

Date: ________________ **Subject Code:** RUCK_UWM_________

Testing: **Pre-march**

Age: ____ **Ht:** _____cm **Wt:** _____N **Helmet Wt:**_______Kg **Vest Wt:**_________Kg

HRmax (220-age):________ **Resting HR:**_________

Dominant Leg: **Left** **Right**

	Trial 1	**Trial 2**	**Trial 3**	**Best of 3**
Maximum Vertical Jump (m)				

	Trial 1	**Trial 2**	**Trial 3**	**Mean**
Inversion (kg)				
Eversion (kg)				
Dorsiflexion (kg)				
Plantarlexion (kg)				

Testing: **Ruck March**

Mile	**HR**	**RPE**	**Talk Test**	**Time (min.)**
0.5 (lap 4)			**YES LP EQ NEG**	
1 (lap 8)			**YES LP EQ NEG**	
1.5 (lap 12)			**YES LP EQ NEG**	
2 (lap 16)			**YES LP EQ NEG**	
2.5 (lap 20)			**YES LP EQ NEG**	
3 (lap 24)			**YES LP EQ NEG**	
3.5 (lap 28)			**YES LP EQ NEG**	
4 (END lap 29)			**YES LP EQ NEG**	

To be transferred from GAITRite computer

Mile	Step Length (m)		Stride Length		Cadence (steps/min)	Velocity (m/s)
	L	R	L	R		
0.5 (lap 4)						
1 (lap 8)						
1.5 (lap 12)						
2 (lap 16)						
2.5 (lap 20)						
3 (lap 24)						
3.5 (lap 28)						
4 END (lap 29)						

Post-March HR (collected in the lab)____________

Testing: Post-march

	Trial 1	Trial 2	Trial 3	Best of 3
Maximum Vertical Jump (m)				

	Trial 1	Trial 2	Trial 3	Mean
Inversion (kg)				
Eversion (kg)				
Dorsiflexion (kg)				
Plantarflexion (kg)				

APPENDIX F: RAW DATA

Participant Code	Collection Date	Age	Sex	Hight (m)	Weight (N)	Weight (Kg)	Helmet Wt. (kg)	Vest Wt. (kg)	HRmax	Resting HR	Dom. Leg.
Ruck_UWM_001	4/27/16	23	Male	1.86	1003.69	102.42	1.7	4.4	197	67	Right
Ruck_UWM_002	4/28/16	21	Male	1.62	571.46	58.31	1.5	4	199	70	Right
Ruck_UWM_003	4/29/16	18	Male	1.8	650.37	66.36	1.5	3.5	202	47	Right
Ruck_UWM_004	4/29/16	20	Male	1.7425	643.35	65.65	1.5	3.3	200	62	Right
Ruck_UWM_005	5/4/16	22	Female	1.79	570.01	58.16	1.5	3.5	198	61	Right
Ruck_UWM_006	5/7/16	22	Male	1.68	570.16	58.18	1.5	3.6	198	58	Right
Ruck_UWM_007	5/11/16	20	Female	1.725	595.71	60.79	1.5	3.2	200	64	Right
Ruck_UWM_008	5/11/16	21	Male	1.86	731.07	74.60	1.5	3.7	199	63	Right
Ruck_UWM_009	5/11/16	22	Male	1.85	862.08	87.97	1.5	3.6	198	79	Right
Ruck_UWM_010	5/17/16	21	Male	1.87	861.46	87.90	1.5	3.6	199	57	Right
Ruck_UWM_011	5/22/16	20	Male	1.865	620.97	63.36	1.5	3.8	200	67	Right
Ruck_UWM_012	6/9/16	20	Male	1.94	850.97	86.83	1.6	3.8	200	61	Right
Ruck_UWM_013	6/9/16	19	Female	1.68	574.66	58.64	1.4	3.6	201	72	Right
Ruck_UWM_014	6/20/16	22	Female	1.575	720.22	73.49	1.6	3.6	198	60	Right
Ruck_UWM_015	6/21/16	30	Female	1.67	687.77	70.18	1.6	3.6	190	61	Right

	Forces						Pre-March Vertical Jump (m)			
Participant Code	Peak-Pre	Peak-Post	TTP-Pre	TTP-Post	LR-Pre	LR-Post	Pre VJ 1	Pre VJ 2	Pre VJ 3	Best Pre VJ
Ruck_UWM_001	1846.3897	2008.99565	128.2	136	14.4553405	14.7963477	0.36	0.37	0.36	0.37
Ruck_UWM_002	1390.98472	1559.30452	119	115	11.7413291	13.5624933	0.6	0.59	0.59	0.6
Ruck_UWM_003	1344.98488	1503.1665	117.166667	92.2	11.530104	16.3576389	0.55	0.58	0.47	0.55
Ruck_UWM_004	1433.96445	1446.42305	109.2	101	13.2853124	14.4149397	0.54	0.53	0.52	0.54
Ruck_UWM_005	1221.41376	1295.20715	110	103	11.1104078	12.5800293	0.34	0.34	0.35	0.35
Ruck_UWM_006	1405.92371	1446.18462	101	98	14.0576088	14.8127188	0.56	0.54	0.53	0.57
Ruck_UWM_007	1215.5218	1283.20957	111.4	103.8	10.9638228	12.3644548	0.41	0.39	0.39	0.41
Ruck_UWM_008	1318.77769	1521.43035	114.8	108.8	11.6076667	14.0680714	0.42	0.39	0.41	0.42
Ruck_UWM_009	1511.33997	1620.17551	105.4	86.2	14.5381254	19.1127954	0.38	0.41	0.4	0.41
Ruck_UWM_010	1582.23589	1629.04255	120.2	119.6	13.1715586	13.6434776	0.33	0.33	0.32	0.33
Ruck_UWM_011	1777.39116	1838.54863	110.6	122.6	16.1408026	15.4346159	0.48	0.51	0.5	0.51
Ruck_UWM_012	1316.9334	1369.53875	103.8	97	12.7005674	14.1459417	0.49	0.49	0.49	0.49
Ruck_UWM_013	1316.9334	1369.53875	103.8	97	12.7005674	14.1459417	0.36	0.31	0.29	0.36
Ruck_UWM_014	1236.49033	1254.44034	105.8	111.5	11.6879783	11.4592754				
Ruck_UWM_015	1402.36138	1428.95645	109.4	113.6	12.833304	12.604895	0.2	0.15	0.16	0.2

	Pre-March Inversion Strength (kg)				Pre-March Eversion Strength (kg)			
Participant Code	**Pre-INV 1**	**Pre-INV 2**	**Pre-INV 3**	**Pre-INV mean**	**Pre-EV 1**	**Pre-EV 2**	**Pre-EV 3**	**Pre-EV mean**
Ruck_UWM_001	24.8	21.9	28.8	25.16666667	24.4	26.9	23	24.76666667
Ruck_UWM_002	21.9	21.7	22.5	22.03333333	26.4	30.2	28.3	28.3
Ruck_UWM_003	16.8	21.1	13.4	17.1	18.3	21.1	20.7	20.03333333
Ruck_UWM_004	20.4	22.2	21.1	21.23333333	23.8	21.3	22.7	22.6
Ruck_UWM_005	21.8	23.7	20.4	21.96666667	22	22.8	23.5	22.76666667
Ruck_UWM_006	29.1	24.8	25.2	26.36666667	27.9	25.9	24.8	26.2
Ruck_UWM_007	15.8	18	17.9	17.23333333	18.5	19.5	18	17
Ruck_UWM_008	18.3	14.2	16.2	16.23333333	26.8	24.8	19.7	23.76666667
Ruck_UWM_009	21.3	22.3	21.1	21.56666667	25.1	25.6	26.6	25.76666667
Ruck_UWM_010	18.8	19.8	20.4	19.66666667	23.8	25.3	20.8	23.3
Ruck_UWM_011	22.2	23.8	19.4	21.8	19.6	19	22.8	20.46666667
Ruck_UWM_012	18	15.2	16.5	16.56666667	18.6	21.5	19.8	19.96666667
Ruck_UWM_013	11.3	8.4	8.9	9.533333333	20.9	17.9	18.2	19
Ruck_UWM_014	17.1	17.5	17.1	17.23333333	17.3	18.8	20.3	18.8
Ruck_UWM_015	16.4	17.5	14.7	16.2	14.1	15.9	15.4	15.13333333

	Pre-March Dorsiflexion Strength (kg)				Pre-March Plantarflexion Strength (kg)			
Participant Code	**Pre-DF 1**	**Pre-DF 2**	**Pre-DF 3**	**Pre-DF mean**	**Pre-PF 1**	**Pre-PF 2**	**Pre-PF 3**	**Pre-PF mean**
Ruck_UWM_001	19.5	21.8	24.7	22	60.5	58.4	58.6	59.16666667
Ruck_UWM_002	25.5	25.9	28.1	26.5	40.1	42	44.4	42.16666667
Ruck_UWM_003	22.3	24.9	23.8	23.66666667	37.6	38.9	36.7	37.73333333
Ruck_UWM_004	27.3	25.9	25.1	26.1	57.3	52.9	62	57.4
Ruck_UWM_005	22.3	20.7	20.7	21.23333333	52.4	49.5	47.5	49.8
Ruck_UWM_006	26.6	27	27.7	27.1	58	54.9	49.5	54.13333333
Ruck_UWM_007	17.5	17.6	17.1	17.4	67.5	58.8	50.3	58.86666667
Ruck_UWM_008	24.9	25	25.2	25.03333333	64.9	60.8	54.4	60.03333333
Ruck_UWM_009	31.4	27.3	27.3	28.66666667	74.1	68.3	67.3	69.9
Ruck_UWM_010	29.4	25.5	30.1	28.33333333	64.4	59.4	68.2	64
Ruck_UWM_011	29.3	26.3	25.4	27	58.4	57.8	59.8	58.66666667
Ruck_UWM_012	21.6	22.5	25	23.03333333	53.7	59	51.3	54.66666667
Ruck_UWM_013	20.8	18.3	18.4	19.16666667	53.2	45.2	58.9	52.43333333
Ruck_UWM_014	23.4	22.4	25.7	23.83333333	42.5	49	47.3	46.26666667
Ruck_UWM_015	24.3	24.4	22.4	23.7	58.6	58.7	66.2	61.16666667

	Heart Rate								
Participant Code	**HR 4**	**HR 8**	**HR 12**	**HR 16**	**HR 20**	**HR 24**	**HR 28**	**HR 29**	**HR post**	**HR Mean**
Ruck_UWM_001	127	127	132	132	138	140	139	143	142	135.55556
Ruck_UWM_002	167	171	171	171	173	174	176	181	181	173.88889
Ruck_UWM_003	153	161	162	162	162	163	161	157	149	158.88889
Ruck_UWM_004	140	145	150	155	154	154	158	155	145	150.66667
Ruck_UWM_005	150	151	158	162	164	163	155	157	148	156.44444
Ruck_UWM_006	142	159	160	161	160	166	172	170	159	161
Ruck_UWM_007	151	151	164	157	160	171	170	171	153	160.88889
Ruck_UWM_008	141	143	155	167	173	180	182	182	182	167.22222
Ruck_UWM_009	138	150	154	158	162	161	160	162	156	155.66667
Ruck_UWM_010	142	151	161	166	169	174	175	174	164	164.03395
Ruck_UWM_011	133	131	134	134	126	133	139	135	137	133.55556
Ruck_UWM_012	146	143	151	160	158	164	166	164	165	157.44444
Ruck_UWM_013	160	156	159	157	160	158	163	164	152	158.77778
Ruck_UWM_014	187	197	200	201	199	200	198	199	191	196.88889
Ruck_UWM_015	160	160	160	172	170	170	174	172	163	166.77778

	Percentage of Heart rate Maximum									
Participant Code	**%HRM 4**	**%HRM 8**	**%HRM 12**	**%HRM 16**	**%HRM 20**	**%HRM 24**	**%HRM 28**	**%HRM 29**	**%HRM post**	**%HRM Mean**
Ruck_UWM_001	0.6446701	0.6446701	0.6700508	0.6700508	0.7005076	0.7106599	0.7055838	0.7258883	0.720812183	0.688099267
Ruck_UWM_002	0.839196	0.8592965	0.8592965	0.8592965	0.8693467	0.8743719	0.8844221	0.9095477	0.909547739	0.873813512
Ruck_UWM_003	0.7574257	0.7970297	0.8019802	0.8019802	0.8019802	0.8069307	0.7970297	0.7772277	0.737623762	0.786578658
Ruck_UWM_004	0.7	0.725	0.75	0.775	0.77	0.77	0.79	0.775	0.725	0.753333333
Ruck_UWM_005	0.7575758	0.7626263	0.7979798	0.8181818	0.8282828	0.8232323	0.7828283	0.7929293	0.747474747	0.790123457
Ruck_UWM_006	0.7171717	0.8030303	0.8080808	0.8131313	0.8080808	0.8383838	0.8686869	0.8585859	0.803030303	0.813131313
Ruck_UWM_007	0.755	0.755	0.82	0.785	0.8	0.855	0.85	0.855	0.765	0.804444444
Ruck_UWM_008	0.7085427	0.718593	0.7788945	0.839196	0.8693467	0.9045226	0.9145729	0.9145729	0.914572864	0.840312674
Ruck_UWM_009	0.6969697	0.7575758	0.7777778	0.7979798	0.8181818	0.8131313	0.8080808	0.8181818	0.787878788	0.786195286
Ruck_UWM_010	0.7158012	0.7590731	0.8076494	0.8324958	0.8484087	0.8763261	0.8785595	0.8763261	0.823981016	0.824291209
Ruck_UWM_011	0.665	0.655	0.67	0.67	0.63	0.665	0.695	0.675	0.685	0.667777778
Ruck_UWM_012	0.73	0.715	0.755	0.8	0.79	0.82	0.83	0.82	0.825	0.787222222
Ruck_UWM_013	0.7960199	0.7761194	0.7910448	0.7810945	0.7960199	0.7860697	0.8109453	0.8159204	0.756218905	0.789939193
Ruck_UWM_014	0.9444444	0.9949495	1.010101	1.0151515	1.0050505	1.010101	1	1.0050505	0.964646465	0.994388328
Ruck_UWM_015	0.8421053	0.8421053	0.8421053	0.9052632	0.8947368	0.8947368	0.9157895	0.9052632	0.857894737	0.877777778

	Talk Test							
Participant Code	**TT 4**	**TT 8**	**TT 12**	**TT 16**	**TT 20**	**TT 24**	**TT 28**	**TT 29**
Ruck_UWM_001	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_002	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_003	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_004	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_005	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_006	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_007	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_008	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_009	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_010	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_011	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_012	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_013	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_014	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Ruck_UWM_015	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

	Time								
Participant Code	**Min. 4**	**Min. 8**	**Min. 12**	**Min. 16**	**Min. 20**	**Min. 24**	**Min. 28**	**Min. Total**	**Avg Time/Lap**
Ruck_UWM_001	502.02	982.02	1465.02	1951.98	2416.02	2884.02	3355.98	3469.98	119.6544828
Ruck_UWM_002	493.98	979.98	1465.02	1951.98	2410.02	2929.98	3406.98	3529.02	121.6903448
Ruck_UWM_003	454.98	922.98	1401	1762.02	2248.98	2746.02	3255	3390	116.8965517
Ruck_UWM_004	475.98	955.98	1432.98	1891.98	2376	2859	3333	3456	119.1724138
Ruck_UWM_005	505.98	946.02	1399.02	1741.02	2197.8	2664	3121.98	3262.02	112.4834483
Ruck_UWM_006	498	987	1474.98	1966.98	2461.02	2925	3394.02	3510	121.0344828
Ruck_UWM_007	520.02	1017	1507.02	1999.98	2610	3199.02	3601.02	3780	130.3448276
Ruck_UWM_008	487.02	993	1471.98	1944	2382	2838	3267	3376.02	116.4144828
Ruck_UWM_009	490.02	969	1402.98	1891.02	2347.02	2808	3270	3385.98	116.757931
Ruck_UWM_010	453	919.98	1380	1837.02	2293.02	2743.98	3163.98	3261	112.4482759
Ruck_UWM_011	474	955.02	1570.02	2035.98	2521.02	2998.98	3466.98	3586.98	123.6889655
Ruck_UWM_012	462	954	1402.98	1897.98	2382	2874	3364.98	3489	120.3103448
Ruck_UWM_013	499.8	1024.02	1543.98	2074.02	2611.98	3147	3660	3780	130.3448276
Ruck_UWM_014	522	1050	1587	2124	2668.02	3363	3919.98	4060.02	140.0006897
Ruck_UWM_015	499.98	1020	1549.02	2206.98	2740.98	3270	3807	3942	135.9310345

Average Time Per Lap								
Participant Code	**Lap Avg 4**	**Lap Avg 8**	**Lap Avg 12**	**Lap Avg 16**	**Lap Avg 20**	**Lap Avg 24**	**Lap Avg 28**	**Lap Avg 29**
Ruck_UWM_001	125.505	122.7525	122.085	121.99875	120.801	120.1675	119.8564286	119.6544828
Ruck_UWM_002	123.495	122.4975	122.085	121.99875	120.501	122.0825	121.6778571	121.6903448
Ruck_UWM_003	113.745	115.3725	116.75	110.12625	112.449	114.4175	116.25	116.8965517
Ruck_UWM_004	118.995	119.4975	119.415	118.24875	118.8	119.125	119.0357143	119.1724138
Ruck_UWM_005	126.495	118.2525	116.585	108.81375	109.89	111	111.4992857	112.4834483
Ruck_UWM_006	124.5	123.375	122.915	122.93625	123.051	121.875	121.215	121.0344828
Ruck_UWM_007	130.005	127.125	125.585	124.99875	130.5	133.2925	128.6078571	130.3448276
Ruck_UWM_008	121.755	124.125	122.665	121.5	119.1	118.25	116.6785714	116.4144828
Ruck_UWM_009	122.505	121.125	116.915	118.18875	117.351	117	116.7857143	116.757931
Ruck_UWM_010	113.25	114.9975	115	114.81375	114.651	114.3325	112.9992857	112.4482759
Ruck_UWM_011	118.5	119.3775	130.835	127.24875	126.051	124.9575	123.8207143	123.6889655
Ruck_UWM_012	115.5	119.25	116.915	118.62375	119.1	119.75	120.1778571	120.3103448
Ruck_UWM_013	124.95	128.0025	128.665	129.62625	130.599	131.125	130.7142857	130.3448276
Ruck_UWM_014	130.5	131.25	132.25	132.75	133.401	140.125	139.9992857	140.0006897
Ruck_UWM_015	124.995	127.5	129.085	137.93625	137.049	136.25	135.9642857	135.9310345

	Step Length Left (m)								
Participant Code	**StepLeft 4**	**StepLeft 8**	**StepLeft 12**	**StepLeft 16**	**StepLeft 20**	**StepLeft 24**	**StepLeft 28**	**StepLeft 29**	**StepLeft AVG**
Ruck_UWM_001	0.9379	0.997	1.004	1.014	1.014	0.997	1.017	0.986	0.9958625
Ruck_UWM_002	0.888	0.845	0.83	0.851	0.836	0.821	0.813	0.811	0.836875
Ruck_UWM_003	0.865	0.925	0.872	0.922	0.874	0.874	0.862	0.851	0.880625
Ruck_UWM_004	0.857	0.852	0.854	0.847	0.847	0.838	0.846	0.84	0.847625
Ruck_UWM_005	0.8481	0.8481	0.8833	0.8597	0.8596	0.8719	0.8698	0.8024	0.8564
Ruck_UWM_006	0.7957	0.8216	0.8314	0.8073	0.808	0.8338	0.8596	0.8041	0.8201875
Ruck_UWM_007	0.7682	0.8246	0.8446	0.8515	0.832	0.789	0.8237	0.8111	0.8180875
Ruck_UWM_008	0.9131	0.8852	0.8987	0.9432	0.9701	0.9273	0.9027	0.9128	0.9191375
Ruck_UWM_009	0.8035	0.8254	0.8474	0.8544	0.8461	0.8589	0.8717	0.839	0.8433
Ruck_UWM_010	0.8954	0.8954	0.8903	0.925	0.9098	0.8757	0.7939	0.8144	0.8749875
Ruck_UWM_011	0.9829	0.96543	0.9337	0.9392	0.9129	0.8637	0.8713	0.9204	0.92369125
Ruck_UWM_012	0.9137	0.8926	0.9156	0.9386	0.9276	0.8992	0.9236	0.9236	0.9168125
Ruck_UWM_013	0.7778	0.7778	0.7642	0.7693	0.7744	0.7489	0.73345	0.718	0.75515
Ruck_UWM_014	0.7291	0.7384	0.6751	0.7133	0.72595	0.7386	0.7368	0.7212	0.72230625
Ruck_UWM_015	0.8254	0.7621	0.8421	0.8201	0.7991	0.7777	0.8453	0.882	0.819225

	Step Length Right (m)								
Participant Code	**StepRight 4**	**StepRight 8**	**StepRight 12**	**StepRight 16**	**StepRight 20**	**StepRight 24**	**StepRight 28**	**StepRight 29**	**StepRight AVG**
Ruck_UWM_001	0.97	1.028	1.048	1.03	0.993	0.998	1.041	0.981	1.0107375
Ruck_UWM_002	0.861	0.869	0.852	0.856	0.8445	0.833	0.841	0.821	0.8471875
Ruck_UWM_003	0.865	0.888	0.899	0.891	0.861	0.882	0.858	0.809	0.869125
Ruck_UWM_004	0.8574	0.869	0.869	0.868	0.868	0.845	0.862	0.841	0.859925
Ruck_UWM_005	0.8688	0.8688	0.9038	0.883	0.8616	0.8847	0.8861	0.866	0.87785
Ruck_UWM_006	0.7927	0.8554	0.87	0.8081	0.8452	0.8527	0.8602	0.8529	0.84215
Ruck_UWM_007	0.7366	0.8061	0.8194	0.8303	0.8381	0.7934	0.8131	0.813	0.80625
Ruck_UWM_008	0.9086	0.8833	0.878	0.945	0.9488	0.987	0.9271	0.9346	0.92655
Ruck_UWM_009	0.8238	0.8595	0.8847	0.8687	0.8498	0.8601	0.8704	0.8449	0.8577375
Ruck_UWM_010	0.889	0.889	0.8763	0.9348	0.8992	0.8996	0.8075	0.8073	0.8753375
Ruck_UWM_011	0.9213	0.9904	0.9413	0.8968	0.9346	0.927	0.9154	0.9651	0.9364875
Ruck_UWM_012	0.887	0.913	0.9256	0.9382	0.9331	0.8974	0.931	0.931	0.9195375
Ruck_UWM_013	0.7447	0.7447	0.7625	0.7533	0.7441	0.7759	0.7569	0.7379	0.7525
Ruck_UWM_014	0.7582	0.7734	0.7254	0.7745	0.7684	0.7623	0.7095	0.7235	0.7494
Ruck_UWM_015	0.8128	0.7112	0.8203	0.7847	0.7948	0.7818	0.8382	0.8526	0.79955

	Stride Length Left (m)								
Participant Code	**StrideLeft 4**	**StrideLeft 8**	**StrideLeft 12**	**StrideLeft 16**	**StrideLeft 20**	**StrideLeft 24**	**StrideLeft 28**	**StrideLeft 29**	**StrideLeft AVG**
Ruck_UWM_001	1.905	2.021	2.07	2.03	2.001	2.007	2.044	1.959	2.004625
Ruck_UWM_002	1.763	1.716	1.729	1.704	1.6825	1.661	1.686	1.628	1.6961875
Ruck_UWM_003	1.708	1.795	1.766	1.814	1.752	1.746	1.702	1.614	1.737125
Ruck_UWM_004	1.7148	1.717	1.742	1.714	1.716	1.676	1.714	1.679	1.7091
Ruck_UWM_005	1.717	1.717	1.7801	1.7277	1.736	1.7536	1.761	1.6888	1.737742857
Ruck_UWM_006	1.5754	1.678	1.6662	1.5735	1.6532	1.6868	1.7204	1.6573	1.65135
Ruck_UWM_007	1.5052	1.6318	1.6659	1.6823	1.6669	1.5658	1.638	1.6246	1.6225625
Ruck_UWM_008	1.8267	1.7906	1.7768	1.8943	1.9196	1.9151	1.8299	1.8642	1.85215
Ruck_UWM_009	1.6309	1.6866	1.7332	1.7171	1.699	1.7127	1.7264	1.687	1.6991125
Ruck_UWM_010	1.7785	1.7785	1.7682	1.8541	1.8132	1.791	1.6372	1.6543	1.756642857
Ruck_UWM_011	1.9443	1.9549	1.9054	1.8364	1.8404	1.8565	1.7819	1.8823	1.8752625
Ruck_UWM_012	1.8032	1.8092	1.83945	1.8697	1.867	1.7772	1.8249	1.8249	1.82694375
Ruck_UWM_013	1.5175	1.5175	1.5353	1.52655	1.5178	1.5248	1.4907	1.4566	1.51084375
Ruck_UWM_014	1.4938	1.519	1.4237	1.5071	1.5119	1.5167	1.4282	1.441	1.480175
Ruck_UWM_015	1.6387	1.4432	1.6587	1.5922	1.5896	1.5685	1.6844	1.755	1.6162875

	Stride Length Right (m)								
Participant Code	**StrideRight 4**	**StrideRight 8**	**StrideRight 12**	**StrideRight 16**	**StrideRight 20**	**StrideRight 24**	**StrideRight 28**	**StrideRight 29**	**StideRightAVG**
Ruck_UWM_001	1.905	2.032	2.035	2.056	2.009	1.969	2.071	1.978	2.006875
Ruck_UWM_002	1.751	1.715	1.638	1.708	1.6845	1.661	1.646	1.634	1.6796875
Ruck_UWM_003	1.754	1.815	1.781	1.815	1.737	1.755	1.71	1.627	1.74925
Ruck_UWM_004	1.7151	1.721	1.724	1.7014	1.714	1.686	1.708	1.68	1.7061875
Ruck_UWM_005	1.7383	1.7383	1.7873	1.7438	1.7281	1.7604	1.7521	1.6712	1.740171429
Ruck_UWM_006	1.5897	1.6772	1.7014	1.6716	1.6775	1.691	1.7045	1.6903	1.6754
Ruck_UWM_007	1.4987	1.6269	1.6658	1.6795	1.6702	1.6206	1.625	1.6001	1.62335
Ruck_UWM_008	1.8223	1.7694	1.766	1.8883	1.9194	1.9333	1.8309	1.8307	1.8450375
Ruck_UWM_009	1.6288	1.6774	1.7293	1.7315	1.7043	1.7237	1.7431	1.684	1.7027625
Ruck_UWM_010	1.791	1.791	1.7712	1.8671	1.8062	1.7757	1.6004	1.6074	1.745571429
Ruck_UWM_011	1.9436	1.9567	1.8753	1.8893	1.8476	1.761	1.7931	1.8907	1.8696625
Ruck_UWM_012	1.7679	1.8067	1.8478	1.8889	1.8563	1.7972	1.8551	1.8551	1.834375
Ruck_UWM_013	1.577	1.577	1.5307	1.53165	1.5326	1.524	1.49205	1.4601	1.5281375
Ruck_UWM_014	1.487	1.5089	1.3868	1.4845	1.4933	1.5021	1.4849	1.4562	1.4754625
Ruck_UWM_015	1.6275	1.4883	1.663	1.6258	1.5944	1.5785	1.6639	1.7376	1.622375

	Cadence (steps/min.)								
Participant Code	**Cadence 4**	**Cadence 8**	**Cadence 12**	**Cadence 16**	**Cadence 20**	**Cadence 24**	**Cadence 28**	**Cadence Final**	**Cadence Mean**
Ruck_UWM_001	114	114	114	118	116	114	114	115	114.875
Ruck_UWM_002	128	129	135	126	126	126	128	121	127.375
Ruck_UWM_003	137	121	129	126	126	127	119	119	125.5
Ruck_UWM_004	132.6	131.1	134.1	134.1	134.1	131.1	132.6	131.1	132.6
Ruck_UWM_005	129	129	131	130.4	127	127.7	130.4	129.9	129.3
Ruck_UWM_006	124.4	127	129	129.9	127.7	130.9	134.1	131.1	129.2625
Ruck_UWM_007	125.7	129	130.4	129	131	137.6	129	127	129.8375
Ruck_UWM_008	117.6	115.4	120.6	120	123.7	127	132.4	129.5	123.275
Ruck_UWM_009	130.4	132.6	134.8	135.3	134.8	134.8	134.8	132.6	133.7625
Ruck_UWM_010	125.9	125.9	124.1	128.6	127.7	129	168.5	172.4	139.4571429
Ruck_UWM_011	115.4	116.1	119.4	125.7	120.6	124.4	123.3	124.1	121.125
Ruck_UWM_012	120.6	116.1	115.75	115.4	116.1	116.5	115.4	115.4	116.40625
Ruck_UWM_013	131	131	133.9	134.8	135.7	130.4	131	131.6	132.425
Ruck_UWM_014	133.9	135.7	138.9	132.7	130.85	129	140.2	131	134.03125
Ruck_UWM_015	117.6	118.1	120.6	124.5	118.2	121.5	119.4	121.2	120.1375

	Velocity (m/s)							
Participant Code	**Velocity 4**	**Velocity 8**	**Velocity 12**	**Velocity 16**	**Velocity 20**	**Velocity 24**	**Velocity 28**	**Velocity Final**	**Velocity Mean**
Ruck_UWM_001	1.818	1.913	1.963	1.999	1.949	1.889	1.946	1.893	1.92125
Ruck_UWM_002	1.862	1.844	1.89	1.788	1.763	1.738	1.761	1.649	1.786875
Ruck_UWM_003	1.982	1.831	1.888	1.899	1.817	1.846	1.701	1.606	1.82125
Ruck_UWM_004	1.894	1.881	1.925	1.915	1.873	1.839	1.887	1.836	1.88125
Ruck_UWM_005	1.846	1.846	1.953	1.894	1.821	1.873	1.903	1.79	1.868571429
Ruck_UWM_006	1.646	1.775	1.829	1.748	1.759	1.8405	1.922	1.811	1.7913125
Ruck_UWM_007	1.5769	1.753	1.809	1.808	1.825	1.816	1.76	1.719	1.7583625
Ruck_UWM_008	1.786	1.7	1.786	1.888	1.978	2.026	2.009	2.001	1.89675
Ruck_UWM_009	1.769	1.862	1.946	1.938	1.905	1.931	1.957	1.861	1.896125
Ruck_UWM_010	1.874	1.874	1.832	1.996	1.928	1.908	2.245	2.332	2.016428571
Ruck_UWM_011	1.869	1.885	1.866	1.923	1.857	1.856	1.821	1.935	1.8765
Ruck_UWM_012	1.81	1.74	1.7725	1.805	1.803	1.744	1.783	1.783	1.7800625
Ruck_UWM_013	1.669	1.669	1.704	1.7075	1.711	1.657	1.6245	1.592	1.66675
Ruck_UWM_014	1.666	1.702	1.609	1.632	1.623	1.614	1.683	1.578	1.638375
Ruck_UWM_015	1.606	1.46	1.671	1.657	1.57	1.578	1.675	1.752	1.621125

	Post-March Vertical Jump				Post March Inversion Strength				Post March Eversion Strength			
Participant Code	**Post-VJ 1**	**Post-VJ 2**	**Post-VJ 3**	**MAX VJ**	**Post INV 1**	**Post INV 2**	**Post INV 3**	**Post INV Mean**	**Post EV 1**	**Post EV 2**	**Post EV 3**	**Post EV Mean**
Ruck_UWM_001	0.4	0.41	0.47	0.47	24.3	22	23.7	23.33333333	29.8	27.7	26.5	28
Ruck_UWM_002	0.53	0.53	0.54	0.54	19	17.5	15.8	17.43333333	26.9	28.1	26.1	27.03333333
Ruck_UWM_003	0.5	0.5	0.49	0.5	14.7	16.5	15.1	15.43333333	20	17	18.4	18.46666667
Ruck_UWM_004	0.45	0.46	0.45	0.46	22.8	21.8	27.2	23.93333333	24.9	23.5	22.2	23.53333333
Ruck_UWM_005	0.38	0.35	0.35	0.38	24.5	19.7	20.4	21.53333333	20	20.2	21	20.4
Ruck_UWM_006	0.62	0.51	0.46	0.62	20.8	21.7	22.1	21.53333333	25.5	24.1	19.5	23.03333333
Ruck_UWM_007	0.24	0.25	0.2	0.25	12.6	11.3	12.9	12.26666667	19.3	20.9	24.3	21.5
Ruck_UWM_008	0.45	0.44	0.41	0.45	21.2	21.6	21.5	21.43333333	22.3	21.2	19.5	21
Ruck_UWM_009	0.32	0.31	0.32	0.32	20.6	21.3	18.4	20.1	23.7	22.3	22.9	22.96666667
Ruck_UWM_010	0.45	0.45	0.45	0.45	20.6	20.6	24.8	22	27	25	24.5	25.5
Ruck_UWM_011	0.61	0.56	0.58	0.61	21.5	21	18.7	20.4	16.5	16.5	17.2	16.73333333
Ruck_UWM_012	0.44	0.48	0.46	0.48	16.1	13.5	11.8	13.8	27.6	25.3	20.3	24.4
Ruck_UWM_013	0.32	0.3	0.33	0.33	10.4	8.6	6.8	8.6	17.6	15.7	14.1	15.8
Ruck_UWM_014					16	14.5	14.5	15	17.9	19	15.9	17.6
Ruck_UWM_015	0.07	0.08	0.05	0.08	15.1	16.1	14.7	15.3	14.4	17.2	16.9	16.16666667

	Post March Dorsoflexion Strength				Post March Plantarflexion			
Participant Code	Post DF 1	Post DF 2	Post DF 3	Post DF Mean	Post PF 1	Post Pf 2	Post PF 3	Post PF Mean
Ruck_UWM_001	25.9	25.6	26.3	25.93333333	59.5	66.5	54.9	60.3
Ruck_UWM_002	27.4	25.5	25.4	26.1	46.4	44.3	45.8	45.5
Ruck_UWM_003	18.5	18.36	18.7	18.52	30.6	34	35.6	33.4
Ruck_UWM_004	25.2	26.9	23.5	25.2	51.9	48.7	44.1	48.23333333
Ruck_UWM_005	21	20.8	22.1	21.3	54.8	49.7	47.9	50.8
Ruck_UWM_006	19.5	20.7	19.1	19.76666667	57.4	51.7	50.2	53.1
Ruck_UWM_007	19.1	18.2	19.5	18.93333333	48.2	45.9	51.4	48.5
Ruck_UWM_008	21.6	25.4	21.2	22.73333333	52.8	54.3	52.7	53.26666667
Ruck_UWM_009	28.8	21.2	24	24.66666667	70.7	67.5	65.4	67.86666667
Ruck_UWM_010	24.7	25.3	26.1	25.36666667	55	55.6	57.7	56.1
Ruck_UWM_011	21.1	23.7	22.4	22.4	55.5	53.2	58.6	55.76666667
Ruck_UWM_012	25.1	24.3	21.5	23.63333333	58.5	56.1	61.3	58.63333333
Ruck_UWM_013	14	14.6	13.5	14.03333333	44.6	45.5	40.8	43.63333333
Ruck_UWM_014	18.4	20.7	20.3	19.8	38.7	36.2	37.4	37.43333333
Ruck_UWM_015	17.4	14		15.7	52.5	49.2	51.7	51.13333333

	Background Information Questionanaire							
Participant Code	**BSI**	**Hip Injury**	**Knee Injury**	**Ankle/foot Injury**	**Training Limitation (6 mo.)**	**Current Pain/Injury**	**Ortho/insoles**	**Medication**
Ruck_UWM_001	0	0	0	1	0	0	0	Vitamins
Ruck_UWM_002	1	0	1	1	0	0	0	Vitamins
Ruck_UWM_003	0	0	0	0	0	0	0	Whey Prot.
Ruck_UWM_004	0	0	1	0	0	0	0	0
Ruck_UWM_005	1	0	0	0	0	0	1	Vitamins
Ruck_UWM_006	1	0	1	0	0	0	0	Vitamins
Ruck_UWM_007	1	0	0	1	0	0	0	0
Ruck_UWM_008	1	0	0	0	0	0	0	Vit,Prot, Cret
Ruck_UWM_009	1	0	0	0	0	0	0	0
Ruck_UWM_010	1	1	1	1	1	0	0	1
Ruck_UWM_011	1	0	0	0	0	0	0	Vitamins
Ruck_UWM_012	0	0	0	0	0	0	1	Vitamins
Ruck_UWM_013	1	1	0	0	0	0	0	B12
Ruck_UWM_014	0	0	0	1	0	0	0	0
Ruck_UWM_015	0	0	0	0	0	0	0	pro-biotics, wo

	Background Information Questionanaire					
Participant Code	**Extra ROTC**	**Other Training**	**Boot Brand**	**ROTC Year**	**Basic Training?**	**APFT Score**
Ruck_UWM_001	PT Wed/Fri	0	Bates	2	0	230
Ruck_UWM_002	0	lift 7x body builder	Nike	2	1	290
Ruck_UWM_003	0	lift 4x run 3x	Std. Issue	1	0	294
Ruck_UWM_004	Ranger	lift 3x run 3x	Rocky	2	0	300
Ruck_UWM_005	Ranger	lift 2x Run 3x	Rocky	4	0	300
Ruck_UWM_006	Ranger	4x	Std. Issue	4	0	300
Ruck_UWM_007	10mile run	alternating st & run 7x	Tactical Research (minimalist)	2	0	294
Ruck_UWM_008	Ranger, German, N. Warfare	lift 3-4x, Run 3x	Rocky	3	1	285
Ruck_UWM_009	Ranger, German, ROTC Bball	lift 5x, run 2x	Reebock, normally Rocky	4	0	300
Ruck_UWM_010	Ranger, Bud. Ranger, Basketball	lift 5-6 run 3x I.M. bball, 1 soccer, 1 football	Garmont	3	0	300
Ruck_UWM_011	Ranger, German	7x run and lift	Rocky	2	0	276
Ruck_UWM_012	Basketball	1x/week lifting	Std. Issue	3	0	271
Ruck_UWM_013	Army 10 mile	Lift 5x/week	Danner	1	0	274
Ruck_UWM_014	0	Run 1x/week	Rocky	4	1	260
Ruck_UWM_015		Run/Lift 4x/week	New Balance	4	1	296

APPENDIX G: ARMY PERSONAL FITNESS TEST SCORING CHARTS

Army Physical Fitness Test Scorecard

For use of this form, see TC 3-22.20; the proponent agency is TRADOC

NAME (Last, First, MI): Smith, Jane A.

GENDER: Female

UNIT: B Company, 199th MI BN

	TEST ONE	TEST TWO	TEST THREE	TEST FOUR
DATE	20091019	20100412		
GRADE	E-6	E-6		
AGE	32	33		
HEIGHT (IN INCHES)	68			
BODY COMPOSITION – WEIGHT (lbs)	140	137		
WEIGHT GO / NO-GO	GO ☒ / NO-GO ☐	GO ☒ / NO-GO ☐	☐ / ☐	☐ / ☐
BODY FAT (%)				
BODY FAT GO / NO-GO	☐ / ☐	☐ / ☐	☐ / ☐	☐ / ☐
PU RAW SCORE	39	42		
INITIALS	FP	FP		
POINTS	92	96		
SU RAW SCORE	72	75		
INITIALS	FP	FP		
POINTS	95	99		
2MR RAW SCORE	15:36			
INITIALS	FP			
POINTS	100			
ALTERNATE AEROBIC EVENT – EVENT		Walk		
TIME		36:39		
GO / NO-GO	GO ☐ NO-GO ☐	GO ☒ NO-GO ☐	GO ☐ NO-GO ☐	GO ☐ NO-GO ☐
TOTAL POINTS	237	195		
NCOIC/OIC SIGNATURE	CPT Sam Jones	CPT Sam Jones		
COMMENTS	Weather: Clear/Temp 76 Humidity 86% Award: APFB	Profile: Ankle Surgery Weather: Clear/Temp 56 Humidity: 66%		

SPECIAL INSTRUCTION: USE INK

LEGEND: PU - PUSH UPS; SU - SIT UPS; 2MR - 2 MILE RUN; APFT - ARMY PHYSICAL FITNESS TEST

DA FORM 705, MAY 2010 PREVIOUS EDITIONS ARE OBSOLETE APD PE v1.00ES

SIT-UP STANDARDS

AGE GROUP Repetitions	17-21 M/F	22-26 M/F	27-31 M/F	32-36 M/F	37-41 M/F	AGE GROUP Repetitions	42-46 M/F	47-51 M/F	52-56 M/F	57-61 M/F	62+ M/F	AGE GROUP Repetitions
82			100			82						82
81			99			81						81
80		100	98			80						80
79		99	97			79						79
78	100	97	96			78						78
77	98	96	95			77						77
76	97	95	94	100	100	76						76
75	95	93	92	99	99	75						75
74	94	92	91	98	98	74						74
73	92	91	90	96	97	73						73
72	90	89	89	95	96	72	100					72
71	89	88	88	94	95	71	99					71
70	87	87	87	93	94	70	98					70
69	86	85	86	92	93	69	97					69
68	84	84	85	91	92	68	96					68
67	82	83	84	89	91	67	95					67
66	81	81	83	88	89	66	94	100	100			66
65	79	80	82	87	88	65	93	99	99			65
64	78	79	81	86	87	64	92	98	98	100		64
63	76	77	79	85	86	63	91	97	97	99	100	63
62	74	76	78	84	85	62	90	96	96	98	99	62
61	73	75	77	82	84	61	89	94	95	97	98	61
60	71	73	76	81	83	60	88	93	94	96	97	60
59	70	72	75	80	82	59	87	92	93	95	96	59
58	68	71	74	79	81	58	86	91	92	94	95	58
57	66	69	73	78	80	57	85	90	91	92	94	57
56	65	68	72	76	79	56	84	89	89	91	92	56
55	63	67	71	75	78	55	83	88	88	90	91	55
54	62	65	70	74	77	54	82	87	87	89	90	54
53	60	64	69	73	76	53	81	86	86	88	89	53
52	58	63	68	72	75	52	80	84	85	87	88	52
51	57	61	66	71	74	51	79	83	84	86	87	51
50	55	60	65	69	73	50	78	82	83	85	86	50
49	54	59	64	68	72	49	77	81	82	84	85	49
48	52	57	63	67	71	48	76	80	81	83	84	48
47	50	56	62	66	69	47	75	79	80	82	83	47
46	49	55	61	65	68	46	74	78	79	81	82	46
45	47	53	60	64	67	45	73	77	78	79	81	45
44	46	52	59	62	66	44	72	76	77	78	79	44
43	44	50	58	61	65	43	71	74	76	77	78	43
42	42	49	57	60	64	42	70	73	75	76	77	42
41	41	48	56	59	63	41	69	72	74	75	76	41
40	39	47	55	58	62	40	68	71	73	74	75	40
39	38	45	54	56	61	39	67	70	72	73	74	39
38	36	44	52	55	60	38	66	69	71	72	73	38
37	34	43	51	54	59	37	65	68	69	71	72	37
36	33	41	50	53	58	36	64	67	68	70	71	36
35	31	40	49	52	57	35	63	66	67	69	70	35
34	30	39	48	50	56	34	62	64	66	68	69	34
33	28	37	47	49	55	33	61	63	65	66	68	33
32	26	36	46	48	54	32	60	62	64	65	66	32
31	25	35	45	47	53	31	59	61	63	64	65	31
30	23	33	44	46	52	30	58	60	62	63	64	30
29	22	32	43	45	50	29	57	59	61	62	63	29
28	20	31	42	44	49	28	56	58	60	61	62	28
27	18	29	41	42	48	27	55	57	59	60	61	27
26	17	28	39	41	47	26	54	56	58	59	60	26
25	15	27	38	40	46	25	53	54	57	58	59	25
24	14	25	37	39	45	24	52	53	56	57	58	24
23	12	24	36	38	44	23	51	52	55	56	57	23
22	10	23	35	36	43	22	50	51	54	55	56	22
21	9	21	34	35	42	21	49	50	53	54	55	21
Repetitions	M/F	M/F	M/F	M/F	M/F	Repetitions	M/F	M/F	M/F	M/F	M/F	Repetitions
AGE GROUP	17-21	22-26	27-31	32-36	37-41	AGE GROUP	42-46	47-51	52-56	57-61	62+	AGE GROUP

Scoring standards are used to convert raw scores to point scores after test events are completed. To convert raw scores to point scores, find the number of repetitions performed in the left-hand column. Next, move right along that row and locate the intersection of the soldier's appropriate age column. Record that number in the Sit-Up points block on the front of the scorecard.

PUSH-UP STANDARDS

AGE GROUP	17-21		22-26		27-31		32-36		37-41		AGE GROUP	42-46		47-51		52-56		57-61		62+		AGE GROUP
Repetitions	M	F	M	F	M	F	M	F	M	F	Repetitions	M	F	M	F	M	F	M	F	M	F	Repetitions
77					100						77											77
76					99						76											76
75			100		98		100				75											75
74			99		97		99				74											74
73			98		96		98		100		73											73
72			97		95		97		99		72											72
71	100		95		94		96		98		71											71
70	99		94		93		95		97		70											70
69	97		93		92		94		96		69											69
68	96		92		91		93		95		68											68
67	94		91		89		92		94		67											67
66	93		90		88		91		93		66	100										66
65	92		89		87		90		92		65	99										65
64	90		87		86		89		91		64	98										64
63	89		86		85		88		90		63	97										63
62	88		85		84		87		89		62	96										62
61	86		84		83		86		88		61	94										61
60	85		83		82		85		87		60	93										60
59	83		82		81		84		86		59	92		100								59
58	82		81		80		83		85		58	91		99								58
57	81		79		79		82		84		57	90		98								57
56	79		78		78		81		83		56	89		96		100						56
55	78		77		77		79		82		55	88		95		99						55
54	77		76		76		78		81		54	87		94		98						54
53	75		75		75		77		79		53	86		93		97		100				53
52	74		74		74		76		78		52	84		92		96		99				52
51	72		73		73		75		77		51	83		91		94		98				51
50	71		71		72	100	74		76		50	82		89		93		97		100		50
49	70		70		71	99	73		75		49	81		88		92		95		99		49
48	68		69		69	98	72		74		48	80		87		91		94		98		48
47	67		68		68	96	71		73		47	79		86		90		93		96		47
46	66		67	100	67	95	70		72		46	78		85		89		92		95		46
45	64		66	99	66	94	69	100	71		45	77		84		88		91		94		45
44	63		65	97	65	93	68	99	70		44	76		82		87		90		93		44
43	61		63	96	64	92	67	97	69		43	74		81		86		89		92		43
42	60	100	62	94	63	90	66	96	68		42	73		80		84		87		91		42
41	59	98	61	93	62	89	65	95	67		41	72		79		83		86		89		41
40	57	97	60	92	61	88	64	93	66	100	40	71		78		82		85		88		40
39	56	95	59	90	60	87	63	92	65	99	39	70		76		81		84		87		39
38	54	93	58	89	59	85	62	91	64	97	38	69		75		80		83		86		38
37	53	91	57	88	58	84	61	89	63	96	37	68	100	74		79		82		85		37
36	52	90	55	86	57	83	60	88	62	94	36	67	98	73		78		81		84		36
35	50	88	54	85	56	82	59	87	61	93	35	66	97	72		77		79		82		35
34	49	86	53	83	55	81	58	85	60	91	34	64	95	71	100	76		78		81		34
33	48	84	52	82	54	79	57	84	59	90	33	63	94	69	98	74		77		80		33
32	46	83	51	81	53	78	56	83	58	88	32	62	92	68	97	73		76		79		32
31	45	81	50	79	52	77	55	81	57	87	31	61	90	67	95	72	100	75		78		31
30	43	79	49	78	50	76	54	80	56	85	30	60	89	66	93	71	98	74		76		30
29	42	77	47	77	49	75	53	79	55	84	29	59	87	65	92	70	96	73		75		29
28	41	76	46	75	48	73	52	77	54	82	28	58	86	64	90	69	95	71	100	74		28
27	39	74	45	74	47	72	51	76	53	81	27	57	84	62	88	68	93	70	98	73		27
26	38	72	44	72	46	74	50	75	52	79	26	56	82	61	87	67	91	69	96	72		26
25	37	70	43	71	45	70	49	73	51	78	25	54	81	60	85	66	89	68	94	71	100	25
24	35	69	42	70	44	68	48	72	50	76	24	53	79	59	83	64	87	67	92	69	98	24
23	34	67	41	68	43	67	47	71	49	75	23	52	78	58	82	63	85	66	90	68	96	23
22	32	65	39	67	42	66	46	69	48	73	22	51	76	56	80	62	84	65	88	67	93	22
21	31	63	38	66	41	65	45	68	47	72	21	50	74	55	78	61	82	63	86	66	91	21
20	30	62	37	64	40	64	44	67	46	70	20	49	73	54	77	60	80	62	84	65	89	20
19	28	60	36	63	39	62	43	65	45	69	19	48	71	53	75	59	78	61	82	64	87	19
18	27	58	35	61	38	61	42	64	44	67	18	47	70	52	73	58	76	60	80	62	84	18
17	26	57	34	60	37	60	41	63	43	66	17	46	68	51	72	57	75	59	78	61	82	17
16	24	55	33	59	36	59	39	61	42	64	16	44	66	49	70	56	73	58	76	60	80	16
15	23	53	31	57	35	58	38	60	41	63	15	43	65	48	68	54	71	57	74	59	78	15
14	21	51	30	56	34	56	37	59	39	61	14	42	63	47	67	53	69	55	72	58	76	14
13	20	50	29	54	33	55	36	58	38	60	13	41	62	46	65	52	67	54	70	56	73	13
12	19	48	28	52	32	54	35	56	37	59	12	40	60	45	63	51	65	53	68	55	71	12
11	17	46	27	50	31	52	34	54	36	57	11	39	58	44	62	50	64	52	66	54	69	11
10	16	44	26	49	29	50	33	52	35	56	10	38	57	42	60	49	62	51	64	53	67	10
9	14	43	25	49	28	49	32	50	34	54	9	37	55	41	58	48	60	50	62	52	64	9
8	13	41	23	48	27	49	31	49	33	53	8	36	54	40	57	47	58	49	60	51	62	8
7	12	39	22	46	26	48	30	49	32	51	7	34	52	39	55	46	56	47	58	49	60	7
6	10	37	21	45	25	47	29	48	31	50	6	33	50	38	53	44	55	46	56	48	58	6
5	9	36	20	43	24	45	28	47	30	48	5	32	49	36	52	43	53	45	54	47	56	5
4	8	34	19	42	23	44	27	45	29	47												
3	6	32	18	41	22	43	26	44	28	45												
2	5	30	17	39	21	42	25	43	27	44												
1	3	29	15	38	20	41	24	41	26	42												
Repetitions	M	F	M	F	M	F	M	F	M	F	Repetitions	M	F	M	F	M	F	M	F	M	F	Repetitions
AGE GROUP	17-21		22-26		27-31		32-36		37-41		AGE GROUP	42-46		47-51		52-56		57-61		62+		AGE GROUP

Scoring standards are used to convert raw scores to point scores after test events are completed. Male point scores are indicated by the M at the top and bottom of the shaded column. Female point scores are indicated by the F at the top and bottom of the unshaded column. To convert raw scores to point scores, find the number of repetitions performed in the left-hand column. Next, move right along that row and locate the intersection of the soldier's appropriate age column. Record that number in the Push-Up points block on the front of the scorecard.

2-MILE RUN STANDARDS

AGE GROUP	17-21		22-26		27-31		32-36		37-41		AGE GROUP	42-46		47-51		52-56		57-61		62+		AGE GROUP
Time	M	F	M	F	M	F	M	F	M	F	Time	M	F	M	F	M	F	M	F	M	F	Time
12:54											12:54											12:54
13:00	100		100								13:00											13:00
13:06	99		99								13:06											13:06
13:12	97		98								13:12											13:12
13:18	96		97		100		100				13:18											13:18
13:24	94		96		99		99				13:24											13:24
13:30	93		94		98		98				13:30											13:30
13:36	92		93		97		97		100		13:36											13:36
13:42	90		92		96		96		99		13:42											13:42
13:48	89		91		95		95		98		13:48											13:48
13:54	88		90		94		95		97		13:54											13:54
14:00	86		89		92		94		97		14:00											14:00
14:06	85		88		91		93		96		14:06	100										14:06
14:12	83		87		90		92		95		14:12	99										14:12
14:18	82		86		89		91		94		14:18	98										14:18
14:24	81		84		88		90		93		14:24	97		100								14:24
14:30	79		83		87		89		92		14:30	97		99								14:30
14:36	78		82		86		88		91		14:36	96		98								14:36
14:42	77		81		85		87		91		14:42	95		98		100						14:42
14:48	75		80		84		86		90		14:48	94		97		99						14:48
14:54	74		79		83		85		89		14:54	93		96		98						14:54
15:00	72		78		82		85		88		15:00	92		95		98						15:00
15:06	71		77		81		84		87		15:06	91		95		97						15:06
15:12	70		76		79		83		86		15:12	90		94		96						15:12
15:18	68		74		78		82		86		15:18	90		93		95		100				15:18
15:24	67		73		77		81		85		15:24	89		92		95		99				15:24
15:30	66		72		76		80		84		15:30	88		91		94		98				15:30
15:36	64	100	71	100	75		79		83		15:36	87		91		93		97				15:36
15:42	63	99	70	99	74		78		82		15:42	86		90		92		97		100		15:42
15:48	61	98	69	98	73	100	77		81		15:48	85		89		91		96		99		15:48
15:54	60	96	68	97	72	99	76	100	80		15:54	84		88		91		95		98		15:54
16:00	59	95	67	96	71	98	75	99	80		16:00	83		87		90		94		97		16:00
16:06	57	94	66	95	70	97	75	99	79		16:06	83		87		89		93		96		16:06
16:12	56	93	64	94	69	97	74	98	78		16:12	82		86		88		92		95		16:12
16:18	54	92	63	93	68	96	73	97	77		16:18	81		85		87		91		94		16:18
16:24	53	90	62	92	66	95	72	97	76		16:24	80		84		87		90		93		16:24
16:30	52	89	61	91	65	94	71	96	75		16:30	79		84		86		90		93		16:30
16:36	50	88	60	90	64	93	70	95	74		16:36	78		83		85		89		92		16:36
16:42	49	87	59	89	63	92	69	94	74		16:42	77		82		84		88		91		16:42
16:48	48	85	58	88	62	91	68	94	[illegible]		16:48	77		81		84		87		90		16:48
16:54	46	84	57	87	61	91	67	93	72		16:54	76		80		83		86		89		16:54
17:00	45	83	56	86	60	90	66	92	71	100	17:00	75		80		82		85		88		17:00
17:06	43	82	54	85	59	89	65	92	70	99	17:06	74		79		81		84		87		17:06
17:12	42	81	53	84	58	88	65	91	69	98	17:12	73		78		80		83		86		17:12
17:18	41	79	52	83	57	87	64	90	69	98	17:18	72		77		80		83		85		17:18
17:24	39	78	51	82	56	86	63	90	68	97	17:24	71	100	76		79		82		84		17:24
17:30	38	77	50	81	55	86	62	89	67	96	17:30	70	99	76		78		81		83		17:30
17:36	37	76	49	80	54	85	61	88	66	96	17:36	70	99	75	100	77		80		82		17:36
17:42	35	75	48	79	52	84	60	88	65	95	17:42	69	98	74	99	76		79		81		17:42
17:48	34	73	47	78	51	83	59	87	64	94	17:48	68	97	73	99	76		78		80		17:48
17:54	32	72	46	77	50	82	58	86	63	94	17:54	67	97	73	98	75		77		80		17:54
18:00	31	71	44	76	49	81	57	86	63	93	18:00	66	96	72	97	74		77		79		18:00
18:06	30	70	43	75	48	80	56	85	62	92	18:06	65	96	71	97	73		76		78		18:06
18:12	28	68	42	74	47	80	55	84	61	92	18:12	64	95	70	96	73		75		77		18:12
18:18	27	67	41	73	46	79	55	83	60	91	18:18	63	94	69	96	72		74		76		18:18
18:24	26	66	40	72	45	78	54	83	59	90	18:24	63	94	69	95	71		73		75		18:24
18:30	24	65	39	71	44	77	53	82	58	89	18:30	62	93	68	94	70		72		74		18:30
18:36	23	64	38	70	43	76	52	81	57	89	18:36	61	92	67	94	69		71		73		18:36
18:42	21	62	37	69	42	75	51	81	57	88	18:42	60	92	66	93	69		70		72		18:42
18:48	20	61	36	68	41	74	50	80	56	87	18:48	59	91	65	92	68		70		71		18:48
18:54	19	60	34	67	39	74	49	79	55	87	18:54	58	90	65	92	67		69		70		18:54
19:00	17	59	33	66	38	73	48	79	54	86	19:00	57	90	64	91	66	100	68		69		19:00
19:06	16	58	32	65	37	72	47	78	53	85	19:06	57	89	63	91	65	99	67		68		19:06
19:12	14	56	31	64	36	71	46	77	52	85	19:12	56	89	62	90	65	99	66		67		19:12
19:18	13	55	30	63	35	70	45	77	51	84	19:18	55	88	62	89	64	98	65		67		19:18
19:24	12	54	29	62	34	69	45	76	51	83	19:24	54	87	61	89	63	97	64		66		19:24
19:30	10	53	28	61	33	69	44	75	50	82	19:30	53	87	60	88	62	96	63		65		19:30
19:36	9	52	27	60	32	68	43	74	49	82	19:36	52	86	59	87	62	96	63		64		19:36
19:42	8	50	26	59	31	67	42	74	48	81	19:42	51	85	58	87	61	95	62	100	63		19:42
19:48	6	49	24	58	30	66	41	73	47	80	19:48	50	85	58	86	60	94	61	99	62		19:48
19:54	5	48	23	57	29	65	40	72	46	80	19:54	50	84	57	86	59	93	60	98	61		19:54
20:00	3	47	22	56	28	64	39	72	46	79	20:00	49	83	56	85	58	93	59	98	60	100	20:00
20:06	[illegible]	45	21	55	[illegible]	63	38	71	[illegible]	78	20:06	48	[illegible]	55	84	58	[illegible]	58	97	59	[illegible]	20:06

Time	M	F	M	F	M	F	M	F	M	F	Time	M	F	M	F	M	F	M	F	M	F	Time
20:00	3	[illegible]		[illegible]	28	[illegible]		[illegible]	46	[illegible]		[illegible]	83	[illegible]		[illegible]	93	[illegible]				
20:06	2	45	21	55	26	63	38	71	45	78	20:06	48	83	55	84	58	92	58	97	59	99	20:06
20:12	1	44	20	54	25	63	37	70	44	78	20:12	47	82	55	84	57	91	57	96	58	98	20:12
20:18	0	43	19	53	24	62	36	70	43	77	20:18	46	82	54	83	56	90	57	95	57	98	20:18
20:24		42	18	52	23	61	35	69	42	76	20:24	45	81	53	82	55	90	56	95	56	97	20:24
20:30		41	17	51	22	60	35	68	41	75	20:30	44	80	52	82	55	89	55	94	55	96	20:30
20:36		39	16	50	21	59	34	68	40	75	20:36	43	80	51	81	54	88	54	93	54	95	20:36
20:42		38	14	49	20	58	33	67	40	74	20:42	43	79	51	81	53	87	53	92	53	94	20:42
20:48		37	13	48	19	57	32	66	39	73	20:48	42	78	50	80	52	87	52	91	53	94	20:48
20:54		36	12	47	18	57	31	66	38	73	20:54	41	78	49	79	51	86	51	91	52	93	20:54
21:00		35	11	46	17	56	30	65	37	72	21:00	40	77	48	79	51	85	50	90	51	92	21:00
21:06		33	10	45	16	55	29	64	36	71	21:06	39	77	47	78	50	84	50	89	50	91	21:06
21:12		32	9	44	15	54	28	63	35	71	21:12	38	76	47	77	49	84	49	88	49	90	21:12
21:18		31	8	43	14	53	27	63	34	70	21:18	37	75	46	77	48	83	48	87	48	90	21:18
21:24		30	7	42	12	52	26	62	34	69	21:24	37	75	45	76	47	82	47	87	47	89	21:24
21:30		28	6	41	11	51	25	61	33	68	21:30	36	74	44	76	47	81	46	86	46	88	21:30
21:36		27	4	40	10	51	25	61	32	68	21:36	35	73	44	75	46	81	45	85	45	87	21:36
21:42		26	3	39	9	50	24	60	31	67	21:42	34	73	43	74	45	80	44	84	44	86	21:42
21:48		25	2	38	8	49	23	59	30	66	21:48	33	72	42	74	44	79	43	84	43	86	21:48
21:54		24	1	37	7	48	22	59	29	66	21:54	32	71	41	73	44	79	43	83	42	85	21:54
22:00		22	0	36	6	47	21	58	29	65	22:00	31	71	40	72	43	78	42	82	41	84	22:00
22:06		21		35	5	46	20	57	28	64	22:06	30	70	40	72	42	77	41	81	40	83	22:06
22:12		20		34	4	46	19	57	27	64	22:12	30	70	39	71	41	76	40	80	40	82	22:12
22:18		19		33	3	45	18	56	26	63	22:18	29	69	38	71	40	76	39	80	39	82	22:18
22:24		18		32	2	44	17	55	25	62	22:24	28	68	37	70	40	75	38	79	38	81	22:24
22:30		16		31	1	43	16	54	24	61	22:30	27	68	36	69	39	74	37	78	37	80	22:30
22:36		15		30	0	42	15	54	23	61	22:36	26	67	35	69	38	73	37	77	36	79	22:36
22:42		14		29		41	15	53	23	60	22:42	25	66	35	68	37	73	36	76	35	78	22:42
22:48		13		28		40	14	52	22	59	22:48	24	66	34	67	36	72	35	76	34	78	22:48
22:54		12		27		40	13	52	21	59	22:54	23	65	33	67	36	71	34	75	33	77	22:54
23:00		10		26		39	12	51	20	58	23:00	23	64	33	66	35	70	33	74	32	76	23:00
23:06		9		25		38	11	50	19	57	23:06	22	64	32	66	34	70	32	73	31	75	23:06
23:12		8		24		37	10	49	18	56	23:12	21	63	31	65	33	69	31	73	30	74	23:12
23:18		7		23		36	9	49	17	56	23:18	20	63	30	64	33	68	30	72	29	74	23:18
23:24		5		22		35	8	48	17	55	23:24	19	62	29	64	32	67	30	71	28	73	23:24
23:30		4		21		34	7	48	16	54	23:30	18	61	29	63	31	67	29	70	27	72	23:30
23:36		3		20		34	6	47	15	54	23:36	17	61	28	62	30	66	28	69	27	71	23:36
23:42		2		19		33	5	46	14	53	23:42	17	60	27	62	29	65	27	69	26	70	23:42
23:48		1		18		32	5	46	[illegible]	52	23:48	16	59	26	61	29	64	26	68	25	70	23:48
23:54		0		17		31	4	45	12	[illegible]	23:54	15	59	25	61	28	64	25	67	24	69	23:54
24:00				16		30	3	44	[illegible]	51	24:00	14	58	25	60	27	63	24	66	23	68	24:00
24:06				15		29	2	43	11	50	24:06	13	57	24	59	26	62	23	65	22	67	24:06
24:12				14		[illegible]	1	43	10	49	24:12	12	57	23	59	25	61	23	65	21	66	24:12
24:18				13		28	0	42	9	49	24:18	11	56	22	58	25	61	22	64	20	66	24:18
24:24				12		27		41	8	[illegible]	24:24	10	56	22	57	24	60	21	63	19	65	24:24
24:30				11		26		41	7	47	24:30	10	55	21	57	23	59	20	62	18	64	24:30
24:36				10		25		40	6	47	24:36	9	54	20	56	22	59	19	62	17	63	24:36
24:42				9		24		39	6	46	24:42	8	54	19	56	22	58	18	61	16	62	24:42
24:48				8		23		39	5	45	24:48	7	53	18	55	21	57	17	60	15	62	24:48
24:54				7		23		38	4	45	24:54	6	52	18	54	20	56	17	59	14	61	24:54
25:00				6		22		37	3	44	25:00	5	52	17	54	19	56	16	58	13	60	25:00
25:06				5		21		37	2	43	25:06	4	51	16	53	18	55	15	58	13	59	25:06
25:12				4		20		36	1	42	25:12	3	50	15	52	18	54	14	57	12	58	25:12
25:18				3		19		35	0	42	25:18	3	50	15	52	17	53	13	56	11	58	25:18
25:24				2		18		34		41	25:24	2	49	14	51	16	53	12	55	10	57	25:24
25:30				1		17		34		40	25:30	1	49	13	51	15	52	11	55	9	56	25:30
25:36				0		17		33		40	25:36	0	48	12	50	15	51	10	54	8	55	25:36
25:42						16		32		39	25:42		47	11	49	14	50	10	53	7	54	25:42
25:48						15		32		38	25:48		47	11	49	13	50	9	52	6	54	25:48
25:54						14		31		38	25:54		46	10	48	12	49	8	51	5	53	25:54
26:00						13		30		37	26:00		45	9	47	11	48	7	51	4	52	26:00
26:06						12		30		36	26:06		45	8	47	11	47	6	50	3	51	26:06
26:12						11		29		35	26:12		44	7	46	10	47	5	49	2	50	26:12
26:18						11		28		35	26:18		43	7	46	9	46	4	48	1	50	26:18
26:24						10		28		34	26:24		43	6	45	8	45	3	47	0	49	26:24
26:30						9		27		33	26:30		42	5	44	7	44	3	47	0	48	26:30
Time	M	F	M	F	M	F	M	F	M	F	Time	M	F	M	F	M	F	M	F	M	F	Time
AGE GROUP	17-21		22-26		27-31		32-36		37-41		AGE GROUP	42-46		47-51		52-56		57-61		62+		AGE GROUP

Scoring standards are used to convert raw scores to point scores after test events are completed. Male point scores are indicated by the M at the top and bottom of the shaded column. Female point scores are indicated by the F at the top and bottom of the unshaded column. To convert raw scores to point scores, find the number of repetitions performed in the left hand column. Next, move right along that row and locate the intersection of the soldier's appropriate age column. **In all cases, when a time falls between two point values, the lower point value is used.** Record that number in the 2MR points block on the front of the scorecard.