The Effects of Whole Body Vibration on Low Back Pain During and After a Military Foot March and Foot March Performance

by

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A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
May 2, 2020

Key words: kinesiology, ruck march, EMG, posture, visual analog scale, creatine kinase

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Abstract

Background: Military foot marches are a critical part of operational missions and military training. However, increases in load carriage weight has increased the amount of musculoskeletal injuries (MSI) sustained. MSI from foot marches now account for 17 to 22 percent of all active duty injuries in the US Army. Weight carried during military foot marches are primarily carried on the service members back; thus a majority of these injuries occur to the back, specifically the lower back. Whole body vibration (WBV) has been shown to decrease low back pain in patients with chronic low back issues by increasing core muscle activation and proprioception. Specific aims of the current study are to determine if WBV and/or core exercise training: 1) influences low back pain during and/or after a military foot march; 2) impacts core muscle activation during a military foot march; 3) affects trunk flexion posture during a military foot march; and 4) influences performance time on a military foot march. Methods: A randomized control trial with three groups: WBV and exercise (WBV_{Ex}), exercise (Ex) and a control group was used to evaluate the effects of WBV and exercise on measures of low back pain, performance and recovery during an eight kilometer foot march. Outcome measures: Dependent variables included visual analog scale (VAS), time, creatine kinase (CK), interleukin-6 (IL-6), algometer, posture, electromyography (EMG), heart rate, muscle oxygenation and rate of perceived exertion (RPE). Regardless of group, low back pain, heart rate, muscle oxygenation, and posture increased throughout the weighted foot march. CK and IL-6 increased following the foot march, however only CK remained elevated 48 hours after the foot march. The WBV_{Ex} and Ex group increased performance on foot march two (FM2) as compared to the control group. Additionally, the WBV_{Ex} and Ex interventions had a moderate effect on increasing pain pressure threshold following FM2 as compared to foot march one (FM1). WBV_{Ex} significantly increased posture during FM2. Overall, WBV and/or exercise training may significantly improve foot march performance, posture and increase pain pressure threshold in the low back following a foot march. Additionally, completing multiple foot marches may decrease low back pain associated with foot marches.

Acknowledgements

First and most of all I would like to thank my family for all their love and support throughout this entire process. To my amazing husband, thank you for all of your love, sacrifices and support that pushed me and helped me to chase my dreams. Thank you to my son Will for enduring this whirlwind experience with me. Especially for spending countless hours in the lab with me collecting data. Thank you to my mom, dad, sister Erin, and brothers James and Shawn who supported me throughout this whole process. Thank you to my adviser Dr. Sefton. I appreciate your guidance, expertise and patience throughout my time at Auburn and especially during this dissertation. Thank you to my committee members; Dr. Games, Dr. Goodlett, Dr. Murrah, and Dr. Roper for their guidance in completing this process. Also thank you to Dr. Witte for taking the time to be my outside reader. Thank you to Dr. Rudisill for all the opportunities that she provides to the graduate student in the School of Kinesiology. Thank you to all my fellow doctoral students that I have worked with in the Warrior Research Center. First thank you to Dr. Jeremy McAdam! Thank you for teaching me how to be a doctoral student and a successful researcher. Most importantly though, thank you for being a great friend. Thank you to the current doctoral students of the Warrior Research Center, Aaron, Lily and Gbenga! Thank you for your willingness to help in all aspects of this study and for being great co-workers and friends. Also a big thank you to all the master students and undergraduate students that have helped in completing this study. Finally, thank you too all of the participants who gave their time to completing this study! Without all of you this study would not have been possible

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ADP, Adenosine Diphosphate

ATP, Adenosine Triphosphate

CK, Creatine Kinase

CP, Creatine Phosphate

CM, Centimeter

ECG, Electrocardiogram

ELISA, Enzyme Linked Immunosorbent Assays

EMG, Electromyography

Ex, Exercise Group

FM1, Foot March 1

FM2, Foot March 2

HMMWVs, High Mobility Multipurpose Wheeled Vehicle

IET, Initial Entry Training

IL-6, Interleukin-6

KG, Kilograms

NIRS, Near Infrared Spectroscopy

MCID, Minimal Clinically Important Difference

MOLLE, Modular Lightweight Load-Carrying Equipment

MSI, Musculoskeletal injury

MVIC, Maximum Voluntary Isometric Contraction

PC, Phosphocreatine

RPE, Rate of Perceived Exertion

TNF, Tumor Necrosis Factor

U/L, Units per Liter

VAS, Visual Analog Scale

WBV, Whole Body Vibration

WBV_{Ex}, Whole Body Vibration and Exercise Group

Yrs, Years

Chapter 1: Introduction

Military foot marches are used extensively as part of military training and physical conditioning. Foot marches also play a vital role in completing tactical mission objectives within operational military units. Specifically, foot marches are important for the transport of equipment and personnel to achieve mission objectives. Light infantry units which are sometimes unattached to motorized vehicles are more likely to utilize military foot marches to achieve mission objectives compared to armor units attached to transportation equipment such as the M1A2 Abrams battle tanks, Bradley fighting vehicle or the High Mobility Multipurpose Wheeled Vehicle (HMMWVs). US Soldiers were rarely asked to carry equipment of greater than 30 pounds during military foot marches prior to the United States Civil War.[2] Current light infantry units conducting operations in Afghanistan are required to carry an estimated average load of 101 pounds.[2-4] Investigators found that Soldiers are only carrying mission essential equipment.[3] This suggests the equipment necessary to conduct military operations has changed dramatically.

Increases in load carriage weight have significantly increased the number of non-combat injuries.[5] Soldiers carrying a load of greater than 30 pounds are 50-60 percent more likely to sustain an musculoskeletal injury (MSI).[5] Common MSI sustained during foot marches include blisters, metatarsalgia, stress fractures, knee pain, low-back pain and rucksack palsy.[2,4] These MSI negatively affect Soldiers across the lifetime of their service in the military. Foot marches MSI during Initial Entry Training (IET), equivalent to the beginning of a Soldiers career, account for the highest rate of MSI per man hour.[5] MSI occurring during IET carry over into the Soldier’s operational service time. Foot marches are the second highest mechanism of injury in infantry units.[6]

The majority of the weight carried (load carriage) during military foot marches is carried on the service members back. It is not surprising that 23-38 percent of load carriage MSI occur to the back, followed by the knee and ankle joints.[5,7,8] Rucksacks are bags with straps that are used to carry equipment within the military. Rucksacks with frames and waist belts have been shown to distribute a majority of the weight onto the Soldiers hip when properly used. This reduces the amount of stress placed on the Soldiers shoulders and trapezius.[9] However, this weight shift increases the discomfort in the low back and upper legs.[2] This may be the reason 57 percent of MSI resulting from load carriage are in the lower back.[8] Researchers and military personnel have investigated a variety of carrying techniques with the goal of better distributing load carriage weight. Double packs keep weight closer to the trunk reducing the amount of back pain.[10] However, they also decreased performance, increased hip and neck pain, and limited the range of motion necessary to complete occupational military tasks.[10] Placing the weight higher in the rucksack has been successful in reducing forward body lean, thus decreasing the amount of stress on the lower back.[2,11] However, packing the weight high in the rucksack creates greater postural sway.[2,11] Thus packing the weight lower on the body is recommended for uneven terrain and higher on the body for even terrain.[2,11]

The military has focused on reducing load carriage weight, distance, and pace of foot marches to reduce MSI from foot marches to reduce MSI[5,7] However, these factors are determined by the commander based on the mission objective.[5,6] Research has shown that commanders and Soldiers are only selecting mission essential equipment, however the weight of mission essential equipment has been increasing.[3] Thus it may be equally important to train the Soldiers to be able to carry more equipment to help reduce injury. Therefore a method that strengths a service member to be able to carry heavy loads for longer distance is needed.

Whole Body Vibration (WBV) is an exercise that is performed on either a uniform vertical oscillating platform or a side-alternating vertical oscillating platform.[12] WBV has been used for increasing bone mineral density[13,14] and balance,[13,15] reducing falls in elderly populations,[13] reducing obesity,[16] and rehabilitation of anterior cruciate ligament reconstruction[17] and chronic ankle instability.[18-20] More recently WBV has been used for reducing pain[21-26] and disability[21,23,24,27] in patients with chronic low back pain. This is likely due to WBV's ability to increase core muscle activity[25,28-31] and proprioception.[22,32] WBV has also been shown to increase performance measures such as strength,[33,34] countermovement jumps,[34,35] speed,[36,37] and running economy.[38]

Low physical fitness levels have been shown to increase a Soldiers risk of injury.[39] However, few studies have investigated the effects of physical training on MSI during load carriage. Two or four training foot marches a month increased foot march performance but had no effect on MSI compared to one or no training foot marches.[40] A combination of resistance and endurance training has been shown to increase performance during 3.2 kilometer foot marches.[41] Additionally military training programs, have been shown to increase performance,[42-45] however high injury rates are associated with these military training programs.[46] Thus, the purpose of this study is to determine if WBV decreases low back pain during and after military foot marches and increases military foot march performances. Our specific research aims are:

1. Specific Aim 1: Determine if whole body vibration and/or core exercise training influences low back pain during and/or after a military foot march.
2. Specific Aim 2: Determine if whole body vibration and/or core exercise training impacts core muscle activation during a military foot march.

3. Specific Aim 3: Determine if whole body vibration and/or core exercise training affects trunk flexion posture during a military foot march.
4. Specific Aim 4: Determine if whole body vibration and/or core exercise training influences performance time on a military foot march.

Our hypotheses are:

1. Whole body vibration and core exercise training will decrease low back pain during and following a military foot march as compared to core exercise training alone or no core exercise training.
    a. Whole body vibration and core exercise training will increase rectus abdominis and erector spinae muscle activation during a military foot march as compared to core exercise training alone or no core exercise training.
    b. Whole body vibration and core exercise training will decrease a forward flexion posture during a military foot march as compared to core exercise training alone or no core exercise training.
2. Whole body vibration and core exercise training will decrease performance time for a military foot march as compared to core exercise training alone or no core exercise training.
    a. Whole body vibration and core exercise training will increase muscle oxygenation during a military foot march as compared to core exercise training alone or no core exercise training.
    b. Whole body vibration and core exercise training will decrease the participant’s perceived exertion during a military foot march as compared to core exercise training alone or no core exercise training.

c. Whole body vibration and core exercise training will decrease creatine kinase (CK) and interleukin-6 (IL-6) levels following a military foot march as compared to core exercise training alone or no core exercise training.

Chapter 2: Literature Review

Introduction

Foot marches within the United States Military are essential for both combat and non-combat operations. Foot marches are used to move equipment and personnel across distances and into areas inaccessible by vehicles. Foot marches are characterized by combat readiness, ease of control, adaptability to terrain, slow rate of movement, and increased personal fatigue.[6] Foot marches require a group of service members to advance to a given location with a designated amount of equipment, carried primarily on their back. The rate of speed and amount of weight carried is determined by the unit commander, who prescribes the weight and rate of speed according to the necessary task or stated mission objective. Guidelines set by the North Atlantic Treaty Organization for optimizing physical performance recommend load-carriage weights of 20-30% of body weight in combat operations, and 45% of body weight in non-combat operations.[47] However, Soldiers are often required to carry loads in excess of 45 kg in order to meet mission objectives.[5] Heavy loads during foot marches may increase the risk of MSI seen in Soldiers.[5] The most common MSI related to foot marching are MSI to the back (23-38%), knee (22%) and ankle (19%).[5,8,48] The prevalence of these MSI in military load carriage operations has led commanders and researchers to investigate the causes of these MSI and examine ways that they may be prevented.

Research examining foot march related MSI in the military population has focused on determining intrinsic and extrinsic risk factors. Many studies have looked at how military units might reduce MSI by minimizing marching distance, prescribing a lighter rucksack packing list, and adopting a different boot or rucksack design. However, little work has been completed investigating the impact an intervention training program on reducing low back pain related to ruckmarching.[2] Developing a physical fitness program to reduce foot march related low back pain may be a more feasible option. Minimizing distance and weight or making alterations to rucksacks and boots may prove too difficult or otherwise impractical within an operational or combat environment. This literature review examines the extent to which foot march related low back MSI are observed, the relevant anatomy and physiology of low back pain, and current literature on injury reduction related to military foot marches. This review also discusses WBV and its possible application for reducing low back pain and current measures to assess pain, muscle soreness, muscle activation, performance and muscle damage in a controlled/clinical/field setting.

The Problem

IET is the first training an enlisted service member completes as part of their military career. Foot marches have the highest rate of MSI per man-hours as compared to all other forms of initial military training, during this training.[5] MSI derived from foot marches, in active duty infantry Soldiers account for 17-22 percent of all injuries, the second highest MSI rate activity among all military training techniques.[6] Additionally, MSI from foot marches incur the highest number of limited duty days (missed training days from MSI) compared to all other training MSI.[5] Specifically, these MSI average 36 to 69 limited duty days per MSI.[5] High numbers of limited duty days can be detrimental to military success; decreasing force readiness, unit capability and increasing risk among deployed units in a combat environment.

Lower extremity and back MSI are the most common foot march related MSI.[5,8,48] The highest rate of foot march related MSI occur to the back (23-38%), followed by the knee (22%), and ankle (19%).[5,8,48] Foot march related MSI are a universal concern. In the Australian military the highest reported load-carriage MSI was to the back (23%), with 57% of these MSI specifically effecting the lower back.[8] Lower back foot march related MSI are most likely due to changes in posture and the increased/abnormal adaptations required of the back musculature to maintain the increased weight of the skeletal structure while in motion.

Comprehensive forces on the lumbar spine are approximately 2.5 times body weight, during unloaded gait.[49] However, loads carried by service members or tactical athletes such as firefighter and police officers, require increased energy expenditure, altered gait and posture; ultimately placing additional stresses on the musculoskeletal system.[47] Weight carried via a rucksack on a service members back, shifts the center of mass posteriorly.[50] To compensate for this weight shift, service members often bend forward at the trunk, placing the center of mass over their base of support.[48,50] Increases in trunk flexion may increase the amount of compression and tensile forces experienced in the intervertebral discs.[48,50] When leaning forward the load on the lumbar intervertebral discs is 275kg as compared to 75kg in the supine position and 100kg in an erect position.[51] Additionally, this trunk flexion increases stresses on the muscles and ligaments in the back.[50] The stresses on muscle and ligaments may be further increased by load carriage gait changes, such as increases in double stance time, stride length at toe-off, and increases in ground reaction forces.[50,52] The combination of the stresses on both the back muscles and intervertebral discs may increase the risk back MSI. Probability of MSI is likely increased when load carriage weight and foot march speed increases, creating conditions where the Soldier becomes more quickly fatigued.

Low Back Pain

Low back pain is a common symptom which effects people across the globe. Approximately 80% of people are effected by some form of back pain in their lifetime.[53] The prevalence of low back pain has increased significantly over the past 3 decades[54] and is likely to continue to rise with continued increases in obesity and decreases in physical activity. The majority of low back pain is acute, often lasting only a few days to a week. However, low back pain can become chronic and last several weeks to years if not addressed. Both acute and chronic low back pain may cause severe personal and financial burdens.[54,55] Each year it is estimated low back pain accounts for healthcare expenditures in the range of 50-100 billion dollars, and is the most expensive work related disability.[56-58] Low back pain disproportionally affects women and older populations between the ages of 40-80.[54]

Low back pain is characterized by dull and aching pain to sharp or shooting pain and limited motion. Low back pain can be multidimensional making diagnosis difficult. Up to 85% of low back pain diagnoses cannot be related to a specific pathoanatomical diagnosis and is considered non-specific low back pain.[57] The most common diagnosis of low back pain is a lumbar strain or sprain (70%).[57] More specific diagnosis such as degenerative process of disk and facets, herniated disk, spinal stenosis, fractures and congenital diseases account for a much smaller percentage of low back pain MSI, ranging from <1 to 10% each.

Relevant Structural Anatomy

The vertebral column formed by 33 vertebral bones, assist with postural control and protecting the spinal cord. The vertebral column is broken down into four sections which are each uniquely designed to provide range of motion while protecting the spinal cord and promoting an upright posture. The cervical spine consists of seven vertebrae (C1-C7) which protect the brain stem and spinal cord while supporting the head and providing head and neck movement. The thoracic spine consists of 12 vertebrae (T1-T12), provides the smallest amount of range of motion and greatest amount of protection to the spinal cord and vital organs, via connection to the rib cage. The lumbar spine consists of five vertebrae (L1-L5) and provides more range of motion compared to the thoracic spine, but less than the cervical spine. The lumbar spine vertebrae are designed to support a large portion of the body weight. The sacrum consists of 5 fused bones, articulated to the iliac bones and coccyx.

Twenty-three intervertebral disc are located between each of the vertebrae in the spine. No intervertebral disc is located between the skull and the first vertebrae of the cervical vertebrae or between the first and second vertebrae of the cervical vertebrae. Intervertebral discs increase the range of motion of the spine and absorb shock from longitudinal and rotational forces.[51] Each intervertebral disc is formed by an outer annulus fibrous that increases the overall strength of the disc.[51] The inter layer of the intervertebral disc, the nucleus pulposus is much more flexible due to high concentration of water.[51] The annulus fibrous of the intervertebral disc is innervated with a rich supply of nerves, which account for the high level of pain associated with intervertebral disc injuries such as disc degeneration and herniations.[51]

The muscular system of the posterior trunk is designed to support and stabilize the spine, while providing the dynamic control necessary for motion. Major contributors to motion of the torso and spine include the latissimus dorsi, levator scapulae, rhomboid major, rhomboid minor, trapezius, and erector spinae. The trapezius, rhomboids major and minor contribute to fixation of the thoracic spine along with motion of the scapula. The latissimus dorsi assists with trunk extension, lateral flexion, and pelvic tilts along with motions of the shoulder. The erector spinae are a group of muscles which contribute to extension of the lumbar spine. Additionally, on the anterior portion of the trunk, the rectus abdominis, external and internal obliques contribute to motion at the lumbar spine. Appendix 1 covers each origin, insertion, innervation and action of relevant musculature.

Trunk Activation Patterns: Gait in Healthy versus Chronic Low Back Patients

The trunk muscles provide stability to the upper body in normal gait, to main amount of work is provided by the leg and hip muscles. Changes in trunk muscle activation patterns can effect gait movement with regard to speed, step length, swing and stance time, as well as affect trunk coordination in people with low back pain.[59] Trunk muscles are routinely divided into a local system and global system to assist with activation analysis.[60-62] The local system is composed of muscles attached to the lumbar vertebrae (excluding the psoas muscle) which are constantly activated and responsible for spinal stability.[60-62] The global system is composed of the erector spinae, internal and external obliques, rectus abdominals, quadratus lumborum and psoas, all of which work to initiate movements.[60-62] The global system muscles can be further classified into two functional categories: mobilizers and stabilizers.[60,61] Global mobilizers initiate movement and global stabilizers control and limit movements.[60,61]

The erector spinae has been shown to be contracted at 40% of the gait cycle, throughout the pre-swing phase, and during initiation of gait in a healthy population.[61,63] However, maximal contraction of the erector spinae occurs at 50% of the gait cycle, during heel contact of the contralateral limb.[61] This is likely due to an eccentric contraction of the spine and load transfer along the lumbar spine.[61] Patients with chronic low back pain have shown similar activation patterns however, amplitude of the erector spinae activation is increased during swing phase.[59]

Additionally, erector spinae activation has been shown to activate earlier in the gait phase for patients with chronic low back pain.[59] During periods of increased walking speed, the erector spinae has been shown to have a corresponding increase in amplitude, in a healthy population.[60,61] However, increases in erector spinae activation is more erratic and varied as walking speed is increased among patients with chronic low back pain.[59]

In healthy individuals the rectus abdominis has been shown to be active continuously throughout the gait cycle.[61] However, patients with chronic low back pain have an increase in rectus abdominis activation throughout the gait cycle.[59] It is hypothesized that increases in activation of muscles of the global system are due to reduced stability of the spine, requiring the muscles of the global system to compensate through increased activation.[59]

Trunk Activation Patterns: Load carriage

Trunk activation patterns are influence by load carriage in service members, tactical athletes and recreational backpackers. During load carriage there is an overall increase in trunk stiffness due to co-activation of the trunk extensors and flexors.[4] Activation of the erector spinae is greatest during heel contact of the contralateral side similar to non-load carriage.[64] Contraction of the contralateral erector spinae prevents excessive rotation of the trunk.[64] However, during load carriage, increases in load weight require a greater increase in erector spinae activity in order to minimize and stabilize trunk movement with the added weight.[64] Increases in erector spinae activity throughout load carriage has been shown to be highly dependent on the weight of the load.[52,64] Specifically, increases in erector spinae activation has been observed in participants carrying loads between 29-47 kilograms.[52,65] However, carrying loads less than 15 percent of body weight has been shown to decrease erector spinae activation.[66] Increases in contraction of the erector spinae during heavy load carriage is likely due to an effort to maintain the body's center of mass over their base of support during load carriage. During load carriage, weight is compensated for by trunk forward flexion which is used to maintain a center of mass while walking.[64] Greater activation of the extensor musculature is required to counterbalance forward flexion posture as load carriage weight increases.[64]

The center of mass is shifted posteriorly as weight of the load carriage increases, increasing the need for activation in the rectus abdominis, to counterbalance extension.[67,68] Activation of the rectus abdominis also increased at a rate corresponding to the weight of the load carriage.[67] However, less weight was required to cause increases in rectus abdominis activation compared to the erector spinae .[67] Carrying a backpack of 10% of body weight increases rectus abdominis activation by 20-35%, while 15% of body weight increased rectus abdominis activation by 54-105%.[66,67] Interestingly, changes in activation patterns for the rectus abdominis were different depending on the side of the body, as the right rectus abdominis had a greater activation patterns as weight increased compare to the left side.[66,67] Asymmetrical increases in muscle activation patterns may reduce trunk stabilization, increasing the likelihood of sustaining an MSI due to load carriage.

Injury Reduction in Military Foot Marches

Research investigating reducing MSI during foot marches has focused on intrinsic and extrinsic risk factors, foot march parameters, boot quality, rucksack quality and resistance and endurance training. Intrinsic risk factors such as gender, body weight, ethnicity, body stature and physical fitness influence a service members risk for sustaining an injury during foot marches.[4] Females have been shown to be more likely to be injured during foot marches than their male counter parts.[4] Smaller body stature, body composition and low physical fitness levels may contribute to their increased injury rates.[4] However, differences in gait such as shorter stride length, greater stride frequency and increased double support time between males and females persist even when body size and composition are accounted for.[2] Participants exhibiting a greater lordotic curve may have an increased risk of sustaining a back injury from foot marching.[4] Extrinsic risk factors for foot marches include the weight of the load, foot march distance, frequency of foot marches, and terrain.[4]

MSI associated with foot marches are largely influenced by weight of the load, distance, and pace of the march. Carrying loads of more than 30 pounds increases the risk of MSI by 50 to 64 percent.[5] These rates rise significantly as weight of the load continues to increase.[5] This is likely due to the additional effort exerted to compensate for changes in center of mass and increased muscle fatigue. Additionally, the duration of time the weight is worn on the back negatively impacts the risk of MSI to the Soldier.[5] Wearing the load for greater than four hours has been showed to increase the risk of MSI in deployed service members.[4] Participating in foot marches more than four times a month increase a service member's risk of MSI.[4] Self-paced foot marches decrease the energy requirements compared to forced marches, which may increase fatigue further.[7] Many equations have been derived to predict the energy cost of load-carriage based on speed, grade, body mass and load mass. The Pandolf equation is one the most commonly used equations to predict energy costs, and can be used to predict energy cost over a variety of differing terrains (equation 1).[69] This equation may be important when planning load carriage as part of a mission; however it has several limitations, including not being able to accurately predict downhill walking energy cost or increases in energy cost over time.[2]

$$M_w = 1.5W \times 2.0 \times (W + L) \times (\frac{L}{W})^2 + T \times (W + L) \times (1.5 \times V^2 + 0.35 \times V \times G)$$

Equation 1: Pandolf Equation is used for energy cost during load carriage. Abbreviations: Metabolic Cost Of Walking (M_w), Body Mass (W), Load Mass (L), Terrain Factor (T), Velocity (V), Slope (G)

Terrain that includes, steep rocky hills, sand or snow have also been shown to significantly increase a service members risk of MSI.[4] While these factors are significant considerations for military commanders, foot march parameters (ex. Distance and pace) are primarily influenced by the objectives of the mission. Thus, research into factors which may increase performance on foot marches and reduce MSI rates is important to consider as they may provide a more feasible alternative to military commanders. MSI reduction research has focused on tactics to combat the number of MSI associated with load-carriage. These tactics include improved footwear, changes in the weight distribution of the rucksack, rucksack quality, and aerobic or anaerobic fitness training.[5]

A majority of the weight is distributed across the back during foot marches. The current rucksack that is used by the United States Army is the Modular Lightweight Load-Carrying Equipment (MOLLE) commonly referred to as the "Molly" in the U.S. Army's lexicon.[5] This system consists of a main ruck sack worn on the back, a waist belt, and a vest which is worn across the chest.[5] The MOLLE system is one size for all service members and therefore may create difference weight distributions for various body types. The MOLLE system significantly reduces the amount of weight carried on the shoulders compared to packs without a frame and hip belt.[2] A frameless pack with a 10kgs load has been shown to exert 203 mmHg of pressure on the shoulders, while a pack with a frame exerted only 15 mmHg for the same load.[9] The standard MOLLE system moves the center of mass in the posterior direction. However, increases in trunk flexion to compensation for shifts in center of mass, increase a service members risk of MSI. Thus, research has examined how changing the weight distribution may help keep the center of mass over the feet, to the risk of MSI. Maintaining the load more proximal to the trunk to decrease changes in center of mass has also been show to decrease energy expenditure.[69] Comparisons of weight distribution across the back have shown benefits to both low and high weight on the back. Higher weight distribution decreases the energy cost and forward flexion as compared with a lower weight distribution.[11] Wearing the load higher on even terrain requires less torso muscle force, thus reducing lumbar spine loading.[49] However, carrying the weight higher have a larger effect on destabilization of posture.[11] Carrying the load lower along the back on uneven terrain reduces the force required to move the load by shortening the distance to the low back.[49] Thus, it is recommended that rucksacks are packed with a higher weight distribution on even terrain and low distributed weight be used for uneven terrain.[49,69]

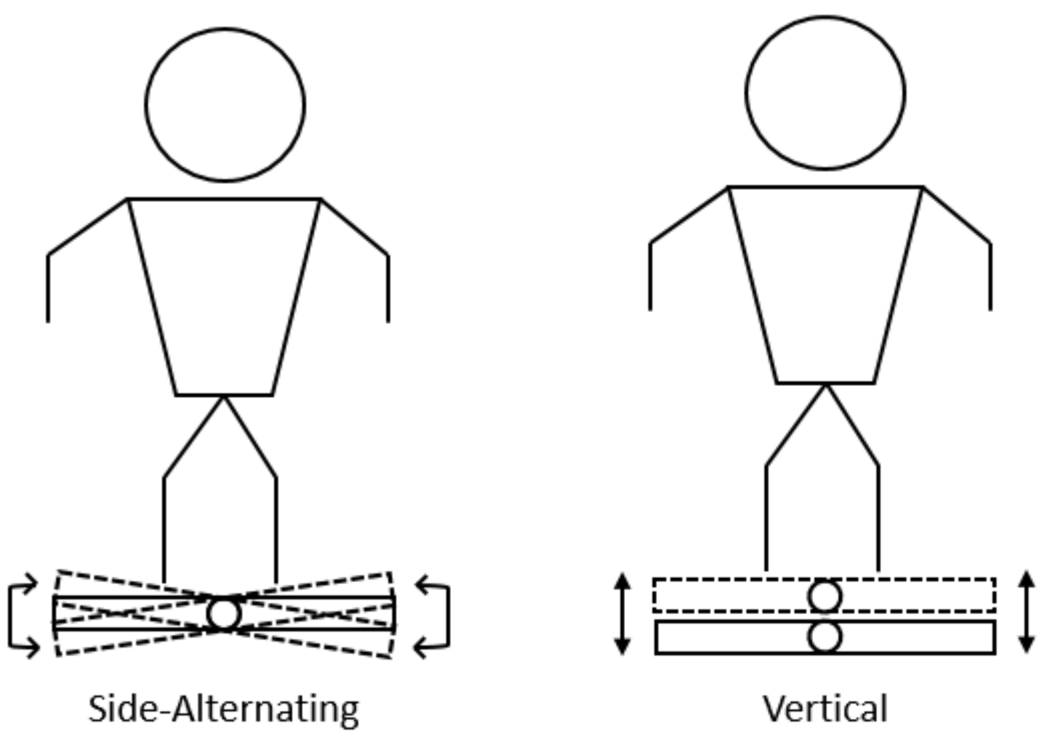
A double pack can be used in an effort to try to keep the center of mass similar to that of an unloaded gait,. A double pack surrounds the service member so weight is distributed over the front and back of the trunk.[10] A double pack decreased back pain and blisters, however the double pack decreased performance and increased neck and hip pain compared to the standard rucksack.[10] Wearing a double pack may not be feasible for many military situations. Double packs may be feasible for medics, where a portion of their pack is carried in the front for access to equipment.[2] However, double pack may hinder cooling and contribute to heat illness, disrupt the field of vision, decrease range of motion, and cannot be easily put on or removed making them unfit for combat situations.[2,69]

Low physical fitness has been shown to increase MSI during basic combat training.[39] As expected, Soldiers with higher $V0_2$ max measures have been shown to have faster performance times in foot marches.[69] It is possible service members with a lower aerobic capacity and/or strength may have an increased risk for low back pain. Service members with a lower aerobic capacity and/or strength may fatigue faster, leading to an altered gait and posture. These compensations may put additional strain on musculature and intervertebral discs, increasing risk of MSI or pain. Thus, is stands to reason that increasing a Soldier's fitness and training with foot marches may decrease overall chance of MSI and increase performance. Several studies have investigated the impacts of military training, aerobic and/or resistance training on foot marches.[40-45,70-74] Several studies in the British and United States Army have evaluated the effects of military training alone on load carriage performance. They found significant increases in load carriage economy and performance following training.[42-45] Similarly, completing two or four foot marches a month has been shown to increase foot march performance when compared to zero or one time per month.[40] Several studies have evaluated the effect of resistance training (upper and/or low body), endurance training, or a combination of training types on foot march performance.[41,72-74] Resistance training alone did not increase foot march performance. However, a combination of resistance training and aerobic training has been shown to increase foot march performance.[41,73,74] Resistance training alone, endurance training alone or a combination of resistance training in a female only population were all able to increase foot march performance.[70-72] To the author's knowledge, no literature has directly examined the specific effects physical training may have on low back pain during load carriage foot marches.

Whole Body Vibration

WBV is a low intensity exercise which has been used for both therapeutic and athletic performance-based outcomes. A WBV platform creates oscillatory motion which is transferred up the kinetic chain. The oscillatory motion is characterized by several parameters including frequency, amplitude and the direction of the oscillating platform. Frequency which is measured in hertz , describes the number of cycles of vibration per second.[75] Amplitude is defined as the difference between the maximum and minimum values of the periodic oscillation.[75] Currently, there are two popular platforms which produce either uniform vertical oscillations or side-alternating vertical oscillations (Figure 1). The frequencies which these platforms can obtain range from 6-60 hertz. Each is capable of amplitudes from <1mm to 10mm.[12]

Figure 1: Side-alternating and vertical vibration



Legend: This figure illustrates the oscillatory motion from Side-alternating and Vertical Vibration

One of the earliest uses of WBV was to improve mobility in patients with osteoporosis. WBV provides a unique intervention for elderly patients with fragile bones, enabling them to complete physical activity in a safe, low intensity exercise. WBV has been shown to increase bone mineral density,[13,14] strength,[13,14] and balance[13] in patients with osteoporosis. Thus, WBV has been used as a mechanism to reduce falls in patients with osteoporosis which may positively impact the patient's overall quality of life.[13] WBV has been used to promote changes in balance, gait, proprioception, strength and overall quality of life in patients with neurological disorders such as stroke, multiple sclerosis, and cerebral palsy.[15] WBV has been selected as a treatment and used as a method of exercise for obese patients who are unwilling or unable to complete light to moderate physical activity.[16] Within active populations WBV has been used as a therapeutic intervention to increase balance and muscular strength for anterior cruciate ligament reconstruction,[17] as well as for treatment of chronic ankle instability.[18-20]

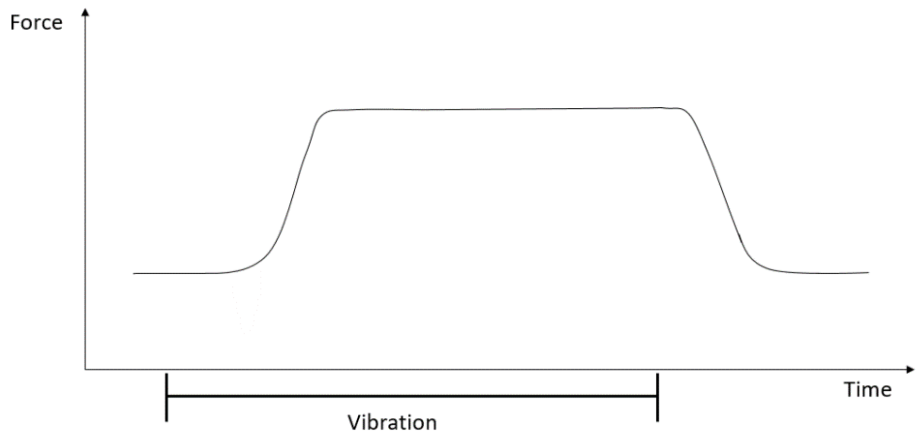
Whole Body Vibration and Muscle Adaptations

Eklund and Hagbarth were the first researchers to define the effect vibration has on muscles in 1965.[76] Vibration causes reflexive muscle contraction, defined as a 'tonic vibration reflex.'[76] A reflex is an involuntary muscle contraction induced by an external stimulus.[1,77] The simple reflex arc involves an afferent (sensory) neuron, central processing unit involving one or multiple synapses, and efferent (motor) neuron.[1] This monosynaptic reflex is the simplest reflex, where the sensory and motor neurons are directly connected. The most common example of this is known as the 'knee jerk' or 'tendon tap,' a routine test in most physician wellness visits.[1,77,78] Muscle spindles, which are located within the muscle, run parallel with extrafusal muscle fibers. These spindles are extremely sensitive to changes in length and velocity of the muscle.[1,77,78]

During the knee jerk reflex, a reflex hammer creates a quick sudden pull on the quadriceps muscle fibers which excites the muscle spindles.[77] Information is sent to the central nervous system via the afferent neurons.[1,77] In the spinal cord sensory neurons act directly on the α-motor neurons which cause a contraction of the quadriceps muscles.[1,77] In a corresponding reciprocal inhibitory response these sensory neurons bring about a relaxation of the antagonist muscle(hamstrings) through interaction with interneurons.[1,77] Reciprocal inhibition decreases co-contraction across the joint allowing the body to move smoothly and efficiently.

The tonic vibration reflex is a polysynaptic reflex, with three or more synapses in the reflex arc.[1] Similar to the tonic stretch reflex, vibration causes a slow stretch of the muscle, activating the muscle spindles.[1,79] Increased muscle spindle activation lead to an activation of motor neurons from the spinal cord.[1] The vibration continues to activate motor neurons, causing tonic muscle contraction.[1] Thus, during vibration muscle contraction slowly increases until a plateau is reached and is maintain until shortly after the vibration has ceased (Figure 2).[1] EMG activity of vibrated muscles shows a similar activation as comparted to a voluntary muscle contraction. However, motor unit firing of a vibrated muscle is synchronistic as compared with asynchronous firing during voluntary muscle contraction.[1] This is likely due to the potent vibration's ability to stimulate all muscle spindles, as I-afferent fibers are large in size, making them more sensitive to direct vibration.[1]

Figure 2: Tonic vibration reflex



Legend: Manual vibration applied to the muscle causes a gradual increase in muscle force until a plateau is reached. (Redrawn from Latash[1])

The tonic vibration reflex has also been shown to occur during low frequency WBV treatment instead of direct vibration.[80] A recent study found at low frequencies WBV treatment was able to create this tonic vibration reflex in both the loaded and unloaded leg.[80] It is believed WBV may lead to increases in neuromuscular adaptations.[81] Increases in muscle spindle sensitivity, and thus α-motor neuron activity, from WBV may lead to neuromuscular adaptations such as; increased motor unit recruitment, increased firing frequency, and improved synchronization.[81] This is consistent with literature which suggests muscle spindles respond to changes in length, as the body communicates information to determine its position in space or proprioception.[77] Increases in muscle spindle sensitivity may cause increases in proprioception.

Based on the tonic vibration reflex, it would be reasonable to assume that long-term usage of vibration, allowing for increased loading on the muscle may lead to morphological changes to increase strength.[81] However to the author's knowledge, no research to date has shown this hypothesized increase in cross-sectional area from long-term vibration use.[81]

Whole Body Vibration and Low Back Pain

Work related high-frequency vibration has been shown to increase back pain.[82] However, more recently low-frequency WBV has been utilized as a method for treating patients with chronic low back pain.[21-27] WBV has been shown to decrease pain,[21-26] disability,[21,23,24,27] increase range of motion,[23] and increase balance in these patients.[21] One study[25] found WBV decreased low back pain in chronic low back patients by an average of two points on the 10 point visual analog scale. Notably, the minimal clinically important difference for the visual analog scale is two, indicating that WBV at low frequencies may be a clinically relevant intervention in patients with chronic low back pain. Decreases in chronic low back pain are hypothesized to come from two primary mechanisms: 1) increases in core muscle activity; and 2) increases in proprioception.[83]

Both acute and chronic WBV have been shown to increase core muscular strength and muscle activation in patients with chronic low back pain.[25,28-31] An acute bout of WBV of only five minutes in chronic low back patients produced a significant increase in erector spinae activity immediately after the WBV intervention while patients were completing flexion and extension exercises.[28] Additionally, the acute effects of WBV on trunk extensor strength have been replicated in a healthy population.[28,31] A two-week WBV intervention study found increases in abdominal strength.[30] A 12-week program investigating the effects of WBV on muscular strength also found increases in both lumbar flexion and extensor muscular strength.[25] Interestingly, even though this program was 12 weeks which is considered beyond the range for strength gains being solely neuromuscular adaptations, there were no documented signs of muscle hypertrophy.[25] This supports previous evidence which indicates WBV strength gains are derived from changes in neuromuscular recruitment patterns rather than muscle hypertrophy.[81]

Patients with chronic low back pain often have difficulty with proprioception, leading to dysfunction and instability of the lumbar spine.[83] WBV has been shown to increase proprioception of the trunk and lumbar spine.[22,32] An acute WBV intervention increased lumbosacral repositioning accuracy an average of 39% in patients with chronic low back pain.[32] One 12-week study measuring position sense found that patients were able to reposition themselves on average within one degree of the intended position, a two degree improvement from tests administered just prior to WBV intervention.[22] This increase may be clinically significant to improve overall stability of the lumbar spine and reduce pain, indicated by a significant reduction in low back pain during this WBV intervention.[22]

Patients with chronic low back pain perform a variety of exercises on the WBV platform. Several studies used WBV with a standing or an isometric squat exercise protocol to reduce low back pain.[21,24,25,27] Other studies have replicated exercises similar to what is commonly prescribed treatment for patients with chronic low back pain in rehabilitation clinics. One study[22] found a decrease in pain and corresponding increase in proprioception by having patients complete isometric squats, kneeling, bridge, bridge with leg lift, bridge and knee flexion and a back release with WBV. Still performed lumbar extension performed on a WBV platform and found decreases in pain and overall.[23] Each of these studies observed and documented decreases in overall pain and/or increases in proprioception from their given WBV intervention exercise. Therefore, it is reasonable to assume a treatment intervention which incorporates some combination of these WBV exercises may be effective in addressing the treatment or prevention of low back pain.

Whole Body Vibration and Performance

WBV has also been used to improve athletic performance in both elite and non-elite athletes. An acute bout of WBV increased both flexibility and countermovement jump performance in female field hockey athletes.[35] WBV has been shown to increasing balance,[84] flexibility,[84] and sprinting speed in soccer players.[36] Additionally, WBV has been used for increasing squat jumps and low limb strength in basketball players.[33] WBV may not improve sport specific tasks such as scoring a goal, but WBV may increase power, strength and agility which can contribute to increases in overall athletic performance.

WBV has been extensively evaluated for effects on gait; specifically as a rehabilitation intervention to improve movement speed and stability during walking.[85] WBV has been shown to improve timed ‘up and go’ test, in elderly patients.[85] Similarly, WBV has been shown to increase walking during the “six minute walking test” in patients recovering from a stroke as well as patients with knee osteoarthritis.[85] However, analyzing WBV’s effect on walking performance within healthy populations has not received extensive study. One preliminary study evaluating the effects of WBV on walking gait found that WBV increases activation of the vastus lateralis, tibialis anterior and the gastrocnemius muscles.[86] Increases in muscle activation in these regions may increase overall walking economy and speed. Increases in gastrocnemius activation were seen in participants with more economical walking, however there was no difference in tibialis anterior muscle activation, among professional race walkers.[87] Core muscle activation during gait is additionally important to performance as it increases stability of the upper body. However no research to date has investigated the effects of WBV on core muscle activation during walking performance.

A few studies which have evaluated the possible effects WBV may have on running performance. An eight week study revealed WBV training improved overall running economy.[38] Specifically, WBV improved caloric unit cost by 5.0 -6.2% and distance unit cost increased by 7.2-8.5%.[38] However, another six-week study evaluating the effects of WBV on running performance found no difference in running performance time following WBV training as compared to strength training.[88] WBV did increase lower body muscular strength in this study.[88] An acute WBV treatment adopted as a warm-up, displayed significant results on step frequency, step length, and flight time when runners began running immediately after WBV in marathon runners.[89] However, decreases in step length, flight time and increases in frequency were similar to what is experienced during fatigue; indicating that ten minutes of WBV prior to running may have caused fatigue.[89] Thus, completing WBV as a sustained workout intervention may be more beneficial to increases in running performance than using WBV as a warm-up.

WBV has also been used as a neuromuscular training tool to increase sprint performance.[37,90] However, the results of these studies vary widely. Previously active individuals improved their 10-60m sprint time significantly, following a six-week intervention program.[37] These participants displayed improvements in step length, step rate, and running velocity.[37] Alternatively, during a five-week training program with sprinting athletes no marked improvements in overall sprint performance were observed.[90] It is important to note that these studies utilized different WBV frequencies, length of training time, and tested two different populations.[37,90] It is possible the differences observed in the outcomes of both studies may be derived from these population differences; as sprint trained athletes have developed a higher reflex sensitivity and do not have the same capacity for growth as a non-active population.[37,90]

WBV has also been used to increase sprint performance as an acute intervention. In an acute intervention, a single study compared the effects of a range of WBV treatments on sprint performance among amateur soccer athletes.[36] Researchers found an increase in performance following 50hz of WBV combined with loaded body squats.[36] However, this result was not replicated at 30 hz.[36] Furthermore, an acute WBV intervention used as a warm-up had no effect on sprint performance in non-elite athletes[91], skeleton athletes,[92,93] or track and field athletes.[94] Study results are likely due to differences in WBV parameters and populations. Only one of the studies[94] use a frequency of 50 hertz of greater, which was previously found to increase sprint speed.[36] The study that used a frequency at 50 hertz[94] used sprint trained track and field athletes likely with less room for improvement.

Effect of Whole Body Vibration on Recovery

Exercise induced muscle damage occurs from participation in exercise or movement to which a person is unaccustomed. Exercise induced muscle damage normally occurs in the initial phases of exercise training programs or during periods of increased training. Both mechanical stress and metabolic stress are responsible for a sequence of inflammatory and immunological events that lead to muscle damage.[95] These events can be separated into 3 phases; autogenic, inflammatory and regenerative phase.[95] Metabolic muscle damage occurs when the rate of adenosine triphosphate (ATP) synthesis does not match ATP hydrolysis.[95] A lack of ATP reduces the muscle ability to maintain contraction causing muscle damage.[95] While muscle damage can occur without mechanical stress, from metabolic stress, mechanical stress is thought to be the primary factor contributing to muscle damage.[95,96] Mechanical stress occurs most often during eccentric exercises since their contractions have lower motor unit activation compared to isometric and concentric exercise.[95,96] Large amount of force over a fewer number of muscle fibers commonly results in deformation of non-contractile proteins.[96] Exercise induced muscle damage results in a loss of muscle function and force production and inflammation.[95,96] Exercise induced muscle damage is measured by increases in CK, and the effects of delayed onset muscle soreness.[75,95,97,98] Typically delayed onset muscle soreness peaks from 24-48 hours post activity, reducing the ability of the individual to perform at peak capability in repeated training sessions.[75] WBV has recently been used to reduce exercise induced muscle damage by substituting WBV as an exercise warm-up or as an active recovery drill. WBV stimulates muscle spindles, as the muscles attempt to dampen the vibration oscillation. This leads to increases in motor unit and muscle fibers being recruited during exercise which in turn increases muscle activation.[75,97] Increases in motor unit and muscle fiber recruitment during repeated exercises may reduce the myofibrillar stress, helping to decrease the amount of exercise induce muscle damage and decreased functionality which accompanies delayed onset muscle soreness.[75,97]

Vibration has been shown to reduce muscle soreness when placed directly on the muscle[99] or on a singular limb[100] to reduce muscle soreness. However, to the author's knowledge only two studies have evaluated these effects within the context of WBV. One study[97] evaluating the effects of one WBV session prior to eccentric exercises found a reduction in loss of maximal strength, CK levels, and muscle soreness. Another study which required participants to perform WBV after the completion of eccentric exercise found a 22-61% decrease in perceived pain.[101] It is possible this effect was due to an increase in blood flow, causing an elimination of waste or an inhibition of pain receptors.[75,101]

Effect of Whole Body Vibration Muscle Oxygenation

Blood flow increases to support the need for the body to move more oxygenation to the active muscles during exercise. WBV has been shown to mimic exercise by increasing blood flow during WBV treatment sessions.[102-105] However, results for increases in muscle oxygenation have been conflicting. A recent study[106] looking at the acute effects of WBV on muscle oxygenation found that muscle oxygenation increased following the second minute of WBV, with the elevation lasting until the completion of the vibration. However, two previous studies[107,108] found that muscle oxygenation did not increase following an acute bout of WBV. It may be that length of time spent on the vibration platform is a key factor in observed increases in muscle oxygenation. A change in muscle oxygenation for the most recent study[106] was not observed until after the completion of the second round of vibration. Alternatively, previous studies evaluated muscle oxygenation after completing a single bout of 110 seconds on the platform.[107,108] Additionally, physically active populations were used in both studies which were shown to be unsuccessful in increasing muscle oxygenation.[107,108] Active populations have been shown to be less sensitive to the effects of WBV as compared to participants who lead a more sedentary lifestyle.[109-111] Lastly, these studies used different measurement devices; near-infrared spectroscopy[107,108] and Humon Hex,[106] which may have influenced the conflicting results. To the author's knowledge, no long -term studies have looked at the effect of WBV on muscle oxygenation.

Intervention

As previously mentioned a variety of WBV exercise intervention programs have been used to successfully reduce low back pain and/or decrease disability.[21-25,27] Included in these differences are the variations in WBV platforms; vertical vibration versus side-alternating vibration. One study[25] evaluated the different effects of vertical and side-alternating WBV on low back pain, lumbar muscle strengthening, balance and functional ability. Results from this study determine that each platform was able to reduce low back pain, decrease disability, increase strength and balance.[25] No difference was found between platforms.[25] Importantly, there was no adverse effects from either platform.[25]

Studies have also successfully used a variety of exercises to reduce low back pain and disability. Several studies used only isometric squats or standing on the WBV to receive the desired outcomes in patients with low back pain.[21,24,25,27] However, one study[22] used a variety of exercises; isometric squats, kneeling, bridge, bridge with leg lift, bridge and knee flexion and a back release that would commonly be utilized in a rehabilitative clinic on the WBV platform. These exercise that focus on core stability and upper body strength may provide better increase of core muscle activity during military foot march and facilitate increased performance.

Studies have also been successfully using a variety of frequencies from 3-34 hertz [21-25,27] and amplitudes from 2-10 millimeters[22,23,28] for their exercises to reduce low back pain. Bridges, planks, side stay and crunches have also been performed on WBV platforms to increase core activity in healthy adults.[112] The rectus abdominis activation was most active during the bridge as compared to the remaining exercises. The erector spinae muscles were activated the greatest during the crunches followed by planks. For each exercise, muscle activity was highest during a frequency of 15 hertz and a low amplitude as compared to lower frequencies on the WBV platform.[112]

Based on the results of the previous studies a combination of these exercises were selected for this study; isometric squats, planks, side planks, bridges, v-ups and back extensions.

1. *Isometric squat:* The isometric squat was chosen for this intervention since it has been successfully used in several studies for decreasing low back pain in chronic low back patients.[21,24,25,27] The squat is a whole body closed kinetic chain exercise that primarily involves muscles of the lower extremity including muscles of the gluteus maximus, vastus lateralis, vastus medialis, biceps femoris and gastrocnemius.[113] Additionally, the squat requires activation of the erector spinae and abdominal muscles to stabilize the pelvis and maintain posture.[114]
2. *Plank:* Plank on the WBV platform has been shown to increase muscle activation of the erector spinae, rectus abdominis, multifidus, external and internal oblique.[112] The plank exercise was selected to strength the rectus abdominis, erector spinae and external obliques.[115,116]
3. *Side Plank:* The side plank exercise was selected to strengthen the rectus abdominis, erector spinae and external obliques.[116] During WBV side planks were shown to increase rectus abdominis and internal and external obliques.[112]
4. *Bridge:* The bridge exercise is used to strength both the abdominal and back extensors, overall increasing trunk stabilization.[116,117] The bridge exercise has been used with a combination of exercises to reduce low back pain in chronic low back patients.[22]
5. *Modified v-up:* The modified v-up is a strength exercise focused on activation of the lower abdominal muscles.[117] Additionally the modified v-up assists maintaining pelvic neutral.[117] Crunch exercises with WBV have been used to increase erector spinae, rectus abdominis, multifidus, external and internal oblique in healthy adults.[112]
6. *Back Extension:* The back extensions were used to strengthen the erectors spinae and rectus abdominis.[118] Additionally the back extension strengthens the hamstrings and

gluteus maximus.[118] Back extension have been used with WBV to reduce low back pain in patients with chronic low back pain.[23]

Measurements

Pain Measurements

Pain is subjective and varies between individuals making pain assessment difficult. However, measuring pain is critical in clinical and laboratory settings to determine the effect of interventions. Pain scales used can be as simple as three-point scales (mild, moderate or severe pain) or larger scales such as a 100 millimeter visual analog scale (VAS).

Visual Analog Scale

The VAS is one of the most commonly used scales to evaluate pain[119] and is also one of the most sensitive scales.[120] The VAS has been used for a variety of injuries and diseases spanning both acute[121] and chronic conditions.[122] The VAS is made up of a straight, 100 mm line in either the horizontal or vertical direction.[123] Both ends of the 100mm line are indicated by verbal markers, indicating “no pain” on one end, and “worst pain imaginable” on the opposite end of the line. Patients are asked to mark a perpendicular (horizontal) line along the scale to indicate their pain level between “no pain” and “worst pain imaginable”.[124] A score is calculated using a ruler to measure the distance from “no pain” to the patient’s perpendicular line. A higher severity of the patient’s pain is indicated by a higher score.

In a clinical setting the VAS has been shown to be a reliable measure of pain.[121] The VAS can also be used to evaluate pain before and after a treatment. In a study evaluating the reliability of the VAS in an acute setting researchers found 90% of patients had a VAS score within 10mm of their previous score.[121] A minimal clinically important difference (MCID) is used to determine if a clinical intervention is meaningful to patients.[125] A MCID of 30mm on the VAS has been determined to correspond to a patients perception of pain control.[126] A MCID of 18mm has been shown to be a meaningful reduction in pain in patients with chronic low back pain,.[127] However, in patients with acute back pain an MCID of 35mm is more meaningful to pain reduction.[127] The visual analog scale has also been used several times to evaluate difference in low back pain following a WBV intervention.[21-25]

Algometry

Pressure algometry has also been used as a measure of pain and muscle soreness.[128,129] An algometer a tool used to evaluate the maximum amount of pressure a patient can endure.[130] Most algometer devices are hand held devices with a rubber application surface, roughly one centimeter wide which can be pushed into the body's soft tissue through the skin.[130] These devices are pushed into the body's surface at a perpendicular angle.[130] The algometer is applied at a constant rate of $1kgcm^{-2}s^{-2}$ to maintain reliability of outcomes between trials.[130] The amount of force applied to the location can be measured as kilograms or in newtons.[128,130] Algometers can be used to evaluate the maximum pressure tolerated or pressure threshold of a patient. Maximum pressure tolerated is assessed by asking the patient to notify the examiner when they can no longer tolerate the pain from the pressure.[128] This method requires algometers, which can apply pressure exceeding 17kgs.[128] Pressure threshold is measured by asking the patient to notify the examiner when they feel any pain or discomfort.[128] This method is generally tolerated better by the participants and has greater reproducibility.[128] Within a clinical setting algometers can also be used to assess and diagnosis myofascial pain dysfunction syndrome, hyperalgesia, and myofascial pain syndrome (trigger points).[130] The algometer has been shown to be both reliable and reproducible for the erector spinae, teres major, upper trapezius, levator scapulae, supraspinatus and gluteus medius muscles.[128,131] Additionally the algometer has been shown to be a valid measure of force as illustrated with a force platform.

Electromyography

Electromyography (EMG) has been used as a technique for measuring muscle activity during biomechanical movements. There are two types of EMG techniques which can be used to capture muscle activity; surface EMG and indwelling EMG.[132] Intramuscular EMG is used to record muscle activity of deep muscular tissue by applying and inserting needles or wire which is pushed through the skin and into the muscle.[132] Surface EMG requires placement of electrodes over the muscle on the skin, and is a less invasive technique for measuring muscle activity of superficial muscles.[132] Surface electrodes must be placed parallel to the muscle fibers and not over tendons.[132] Location of the surface electrode is vital because the EMG relies on capturing the action potentials of the sarcolemma to determine the strength of the muscle contraction.[132,133] During muscle contraction the sarcolemma membrane depolarizes producing an action potential, recorded by the EMG.[133] This action potential precipitates the release of calcium leading to a muscle contraction.[133] The EMG signal created is the combination of multiple action potentials of many motor units in the area of the electrode.[132]

The EMG signal must be processed before being analyzed. Analysis of raw signal involves rectifying the signal, creating a linear envelope, or smoothing and/or integrating the signal.[132] The first step, rectification of the EMG, is used to make all of the EMG signals positive. This is accomplished by taking the absolute values of the signal.[132,133] Rectification allows for standard amplitudes to be applied to the data.[133] Following rectification the data is smoothed to account for the non-reproducible part of the signal.[132,133] There are two primary algorithms for smoothing the rectified raw data: calculating the moving average or calculating the root mean square.[133] Calculating a moving average, averages the data based on a predefined amount of raw data points.[133] The preferred method is that of the root mean square, which takes the square root of the calculation to determine the mean power of the signal. An alternative method, the 'integrated signal' has also been used as a filter but is less common and produces a total accumulation of EMG activity over time.[132] Some studies apply digital filters to create linear envelope EMG.[133] This is especially popular when using fine wire EMG which may be subjected to wire movement artifacts.[133] However, within kinesiology related field studies rectified root mean squared EMG is the commonly used process.[133]

Measurements of EMG are strongly related to the positioning of electrodes and the subject's strength.[132,133] EMG activity is often standardized to a normalized value to compensate for the low reproducibility between subjects and electrode placements.[132,133] EMG is most commonly normalized at the maximum voluntary isometric contraction (MVIC).[133] This test is preformed immediately after the placement of the electrodes prior to recording the EMG for the intervention.[133] Each muscle of interest must have a recorded MVIC coefficient.[133] To accurately measure a MVIC the muscle should be placed in an exercise position which isolates the contraction of the specific muscle to be observed.[133] An isometric contraction is performed against a static resistance in order to achieve a maximal contraction and obtain the MVIC coefficient.[133] When maximal muscle activation is achieved during the MVIC, MVIC normalization can be repeatable and reliable.[134] However, MVIC, commonly do not produce maximal muscle activation to, therefore producing muscle activation percentages greater than

100 percent during normalization.[134] This is most commonly seen in research studies investigating forceful and rapid contractions.[134] Muscle activation patterns greater then 100% overestimate the muscle activation.[134] To reduce overestimation of muscle activation, researcher have normalized EMG signal to the same dynamic task.[134] This method is reliable between trials, however is not valid to comparing separate tasks, since the reference is task dependent.[134]

Common trunk muscles measured during gait include the erector spinae, multifundus, latissimus dorsi, trapezius, quadratus lumborum, rectus abdominis, obliquus externus, obliquus internus, transversus abdominius and iliopsoas.[135] The most common method for electrodes is surface electrodes.[135] There is no current consensus for anatomical placement of EMG electrodes on trunk muscles.[135] Location of the rectus abdominis have ranged from lateral to the umbilicus,[60,136-138] level with the anterior superior iliac spine[139,140] and midway between the xipoid and umbilicus.[141] Placement of the electrodes for the erector spinae have been place along the lumbar spine from the seventh vertebrae of the cervical vertebrae to the fifth vertebrae of the lumbar spine.[63,139,142-144]

Muscle Oxygenation Measurement

Near infrared spectroscopy (NIRS) is the most broadly used technique for measuring muscle oxygenation. NIRS is a light based technique to monitor tissue oxygen levels.[145] Biological tissue is capable of attenuation of visible light, which is light within the spectrum of 450-700nm.[145] The human body is more transparent to near-infrared light (700-1000nm).[145] Visible light can only be detected through 1cm of tissue, whereas near infrared light can be detected through 8cm of tissue.[145] Therefore, NIRS uses a range of near-infrared to penetrate the tissue and calculate levels of oxyhemoglobin and deoxyhemoglobin based on reflection, absorption and scattering levels.[145] NIRS is an important clinically non-invasive technique, however it is not convenient for field measurements of muscle oxygenation levels.[146]

Recently wearable muscle oxygenation monitors have been developed to help athletes optimize performance.[147] Current commercially available devices include the Humon Hex, Moxy Monitor and Portamon.[147] Each of these devices are based on physical principles similar to the NIRS device.[147] Muscle oxygenation saturation, the ratio of oxygenated hemoglobin concentration to total hemoglobin concentration, is displayed via the devices application.[147] The Moxy Monitor and Portamon can be placed on any muscle to measure muscle oxygenation, while the Humon Hex is uniquely designed to be worn on the rectus femoris.[147] Currently the Humon Hex is the only device which has been validated against NIRS technology. The correlation between muscle oxygenation saturation and hemoglobin/myoglobin was greater than 0.86 compared to NIRS assessment.[146]

Rate of Perceived Exertion

The subjectively measured ‘rate of perceived exertion’ has been used as an indicator of an individual’s physiological work rate. The most commonly used scale is the ‘Borgs scale.’ The Borg scale ranges from six to 20 points with six points indicating a feeling of ‘no exertion’ and a score of 20 points indicating a feeling of ‘maximal exertion’. In a cohort of over 2500 men and women, the Borgs scale has been shown to be significantly associated with both lactate and heart rate levels.[148] Additionally, the rate of perceived exertion was not influenced by gender, fitness level or training status.[148]

Measures of Muscle Damage and Inflammation

Measures of muscle damage and inflammation inside the body can be evaluated through biological markers known as biomarkers. Biomarkers are characteristics that are objectively measured to evaluate biological, pathogenic or pharmacologic processes.[149] Biomarkers range from pulse and blood pressure to blood and other body tissues.[149] In athletes biomarkers utilizing proteins, metabolites, electrolytes and other molecules can be used to balance training and recovery. Measures of muscle damage and inflammation to are measured through serum to track an athlete's recovery.

Creatine Kinase (CK)

One of the primary markers used for muscle damage is serum CK. CK is found both in the cytosol and mitochondria.[150] CK in the cytosol is found as both muscle type (M) and brain type (B) with subunits of CK-MB in cardiac muscle, CK-MM in skeletal muscle and CK-BB in the brain.[150] In the mitochondria there are two forms of CK, ubiquitous Mt-CK and sarcomeric Mt-CK.[150] CK also occurs as macroenzymes which are normally expressed during disease.[150]

CK is vitally important to anaerobic ATP production during physical activity. The metabolism of ATP as an immediate energy source is governed by CK. CK can transfer one phosphate from ATP to creatine to create creatine phosphate (CP). Importantly, this reaction is reversible. CK can cleave the phosphate from CP and add it to adenosine diphosphate (ADP) to created ATP which can be used for muscle contraction (Figure 3). Skeletal muscle has a large quantity of CK to facilitation this immediate energy source transformation, accounting for approximately 20% of sarcoplasmic protein in muscles. CK is bound to the M-line of the sarcoplasmic reticulum and located in the space between I-bands.[150]

Figure 3: ATP-PC System

$$\text{ADP} + \text{CP} \xleftrightarrow[\text{Creatine Kinase}]{} \text{ATP} + \text{C}$$

Legend: This figure illustrate the ATP-PC system that provides and immediate energy source for exercise.

Serum CK was originally used as a marker of disease, especially for myocardial infractions. The literature is controversial over the use of CK as a measure of muscle damage.[150] Participation in unaccustomed exercise, especially eccentric exercises, lead to muscle damage.[95,98,150] Muscle damage can occur and be brought about through both mechanical and/or metabolic stress.[95,98] Mechanical stress causes damage to contractile and connective tissue, while metabolic stress increases the release of the adrenaline and cortisol.[95,98] Both stressors lead to oxidative damage, cell damage, influx of proteins and the release of calcium and CK.[95,98,150]

Base levels of CK range from 35-175 units per liter (U/L), however CK can range from 20-16,000 U/L.[150] Levels greater than 5,000 U/L are believed to be indicative of serious muscle damage.[150] Levels ranging from 10,000 to 20,000 are used to diagnosis rhabdomyolysis, a clinical diagnosis of muscle damage which can cause catastrophic renal impairment.[150] Serum CK markers following unaccustomed exercise typically peak between 24-48 hours post physical activity. However it usually takes 7-9 days for serum CK to return to pre exercise levels.[95,97,98,150] Serum CK levels can be influenced by a number of factors, including hydration levels, gender, and age.[150] Given this, it may be important to include measures such a muscle biopsies, patient reported outcomes, and other biomarkers when assessing muscle damage.

Interleukin-6 (IL-6)

The production of cytokines, IL- 1, IL-2, IL-6 and tumor necrosis factor (TNF) are upregulated during exercise.[95] IL-6 has been found to be the most affected by exercise of the cytokines.[95,151,152] Baseline plasma levels of IL-6 is approximately 1pm/ml.[151] Active individuals generally have a lower baseline IL-6 levels than sedentary people.[151] During severe infections IL-6 levels can reach 10000 pg/ml.[151] Following exercise IL-6 levels can increase up 100 fold, but is highly dependent on the type, intensity, and duration of the exercise completed.[151,152] The majority of IL-6 is produced directly from the exercising muscle.[151,152] Specifically IL-6 has been shown to be expressed by myofibers.[153] While the main portion of IL-6 comes from the exercising muscle, IL-6 has also been show to enhance its own transcription in addition to small production from the tendon and jugular vein.[151]

IL-6 plays a major role in the inflammatory response and may be responsible for protein degradation during muscle damage.[153] IL-6 also increases proliferation of satellite cells, and is essential for muscle regeneration and muscle hypertrophy.[154] Marathon runners have been shown to have a 128-fold increase in IL-6 following a race,[155] however following a spartathlon race, a race which is 246km in length - IL-6 was found to increase 8000-fold on average.[156] This uncharacteristically high increase in IL-6 is the perfect example of the importance of type, intensity and duration of exercise for increases in IL-6. Exercises which involve large muscle groups, especially running, is optimal for increases in IL-6.[151] Duration is the most important factor in determining increases in IL-6, as no more than a 10 fold increase has been found in exercises lasting less than 1 hour.[151]

During periods of trauma or disease IL-6 is used as a measure of tissue damage.[157] As a result of this production it has been inferred that IL-6 may also be a measure of muscle damage following unaccustomed exercise. A theoretical model[95] hypothesized that following unaccustomed exercise, mechanical stress, metabolic stress and oxidative damage would lead to an increase in cytokines which mediated the inflammation process or the acute phase response. Since eccentric exercise may produce exercise induced muscle damage to a greater extent than concentric exercise, IL-6 involvement in exercise induced muscle damage has most commonly been measured by comparing eccentric versus concentric exercise. during eccentric exercise in a mouse model,[153] myofibril staining showed a significant increase in IL-6 along with myofibril damage consistent with exercise induce muscle damage. One study compared the effects of concentric vs eccentric exercise on serum IL-6 levels and found a significant increase in IL-6 levels 2 hours after eccentric exercise.[158] Similarly, a significant increase in CK was associated with the increase in IL-6 following the eccentric exercise,[158] indicating that IL-6 may be a measure of muscle damage. A similar study investigating the effects of eccentric exercise on IL-6 found significant increases in IL-6 at periods of 12, 24 and 72 hours post eccentric exercise, the peak period of delayed onset muscle soreness.[159] However, replicated studies have not been able to repeat this extended increase in IL-6. One study,[160] evaluating the effects of eccentric exercise found a significant increase in IL-6 immediately after and 30 minutes post exercise. This study did not find increases in IL-6 24-48 hours after the completion of exercise.[160] Another study found a significant increase in IL-6 up to 6 hours following the completion of eccentric exercise which was significantly related to the increase in delayed onset muscle soreness.[161] However, similar to the previous study, increases were not found 24-48 hours following exercise during the peak of delayed onset muscle soreness.[161] Thus, IL-6 may be a significant initial indicator of the start of muscle damage and delayed onset muscle soreness but inferences beyond this point are less clear.

Conclusions and Purpose Statement

Optimizing a service health and performance is imperative to winning on the modern-day battlefield. Today's Soldiers are often asked to carry ruck sacks exceeding 45kg in weight.[5] MSI from military foot marches account for the most missing or limited training days across the majority of military infantry units.[5] The most common foot march related MSI occur to the back, knee and the ankle.[5,8,48] Research on reducing MSI during foot marches have primarily focused on how to manipulate weight, distance, and pace of foot marches.[5,7,69] A more practical approach may be to increase individual Soldier capability through strength training of the core musculature. This would aide in maintaining a stronger, more erect posture, reducing risk of overall MSI without inhibiting mission success. WBV has been shown to increase core muscle activation [25,28-31] and trunk proprioception.[22,32] Additionally, WBV training has been shown to increase strength,[33] sprinting speed,[36] balance,[84] improve running economy,[38] and improve muscle recovery.[97,101] WBV combined with core exercise training may provide a more practical approach to increase core muscle activation, decrease forward flexion posture, decrease low back pain, and increase Soldier performance during military foot marches.

Chapter 3 Methodology

Design

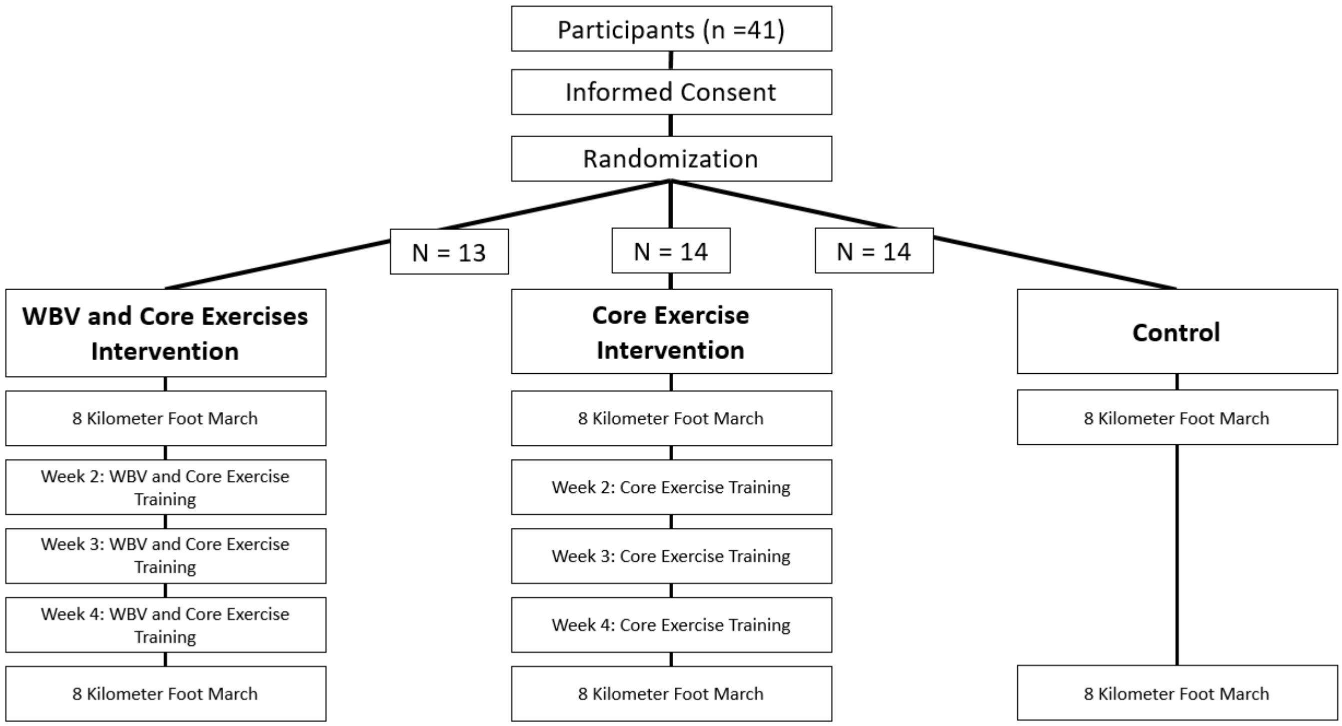
A three by two, repeated measures randomized control trial was used to determine the effect of WBV on performance and low back pain during and after an eight kilometer foot march. The independent variables were groups with three levels (WBV and core exercise, core exercises and control) and time with two levels (initial foot march and post foot march) and five sublevels (pre foot march, four kilometers foot march, post foot march, one day post foot march, two days post foot march). The dependent variables were 100 millimeter VAS scores, algometer scores, muscle activation levels for the rectus abdominis and erector spinae, posture, performance time, heart rate, rate of perceived exertion levels, muscle oxygenation levels, CK levels and IL-6 levels.

Participants

The Auburn University Institutional Review Board (protocol number: 19-211 MR 1907) approved all procedures of this study. Participant were recruited for participation with flyers and a study description on Auburn University College of Education Research Participation System (SONA). All possible participants were briefed on the study by a member of the research team. Participants volunteering to participant in the study completed the consent form (appendix 2). Participants were required to be healthy physically active adults according ACSM guidelines;[162] ages 19-35. Exclusion criteria included acute inflammations or infections, acute joint disorders/arthroses, chronic migraine headaches, cardiovascular diseases, recent joint implants, metal or synthetic implants, gallstones, epilepsy, recent thrombosis or possible thrombotic complaints, current low back complaints, current concussion, concussion with 90 days, and pregnancy.

A power analysis was calculate prior to recruitment from a previous study investigating the effects of WBV on low back pain.[24] Based off of a large effect size seen in the previous study, power of 0.80 and an alpha level of 0.05, nine participants were required for each of the three groups. Forty-one healthy participants between the ages 19-35 were consented to complete this study. Two participants withdrew from the study following the completion of the first foot march. One participant withdrew due to a lack of time to complete all requirements of the study. The second participants withdrew due to foot pain following the first foot march. 39 participants completed the study. Additionally two participants were unable to give blood sample, therefore only 37 serum sample were analyzed. Descriptive for all participants completing the study are located in Table 1.

Figure 4: Overall study design



Legend: This figure illustrates the overall study timeline

Brief Method Overview

Participants were randomly placed in one of three intervention groups; WBV and core exercises (WBV_{Ex}) intervention, core exercise (Ex) intervention or control intervention using a random number generator (Figure 4). Each participant was asked to complete two eight kilometer foot march separated by four weeks. Participants in the WBV_{Ex} and Ex groups completed three weeks of abdominal and core stabilization exercises that begun one week following the first foot march. Participants in the WBV_{Ex} completed the exercises on the WBV platform with vibration. Participants in the Ex group completed the core stabilization exercise on the WBV platform without vibration. The control group was asked to continue their normal daily routine.

The dependent variables of low back pain, perceived exertion and muscle oxygenation were measured prior, at the four kilometer mark, and immediately following each foot march; as well as on the first and second day following each foot march. Muscle soreness and inflammation were measured before, immediately following each foot march, as well as on the first and second day following each foot march. Muscle activation and posture were measure before and during the foot marches. Performance was measured as the time it took to complete each foot march.

Foot March

Participants completed two (pre- and post-intervention) foot marches wearing a 35 pound (15.9 kilogram) rucksack. The rucksack was packed by a United States Infantry Army Lieutenant Colonel with more of the weight packed higher on the back to best mimic load carriage in the military. The foot march was completed around an indoor loop to control for environmental conditions and mimic foot marches completed on even terrain for military operations. Participants were instructed to complete the foot march as fast as they could safely complete the entire march. Participants were able to take breaks and drink water ad libitum for safety.

WBV and Core Stability Exercise

Participants in the WBV_{Ex} and Ex groups completed six core stability exercises three times a week for three weeks. Each exercise was completed for 30 seconds, three times per session with a one minute rest period in between exercises. Each exercise was completed on a side-alternating WBV platform (Galileo Med L, Novotec Medical, Pforzheim, Germany). Both types of WBV platform (side-alternating and vertical) have been shown to decrease pain in chronic low back pain patients with no statistically significant difference between platforms, indication that either platform may be successful in reducing low back pain.[25] A side-alternating platform was selected for this study due to its capability to use a lower frequency range for the core exercises. Completing core exercises that required the participant's head to be close to the platform (ex. plank), during high frequencies (greater than 30 hertz) would increase the amount of vibration transmitted to the participants head. Exercises selected for this study have been previously used for increasing core muscle activation and used in previous studies evaluating the effects of WBV on chronic low back pain.[22,23]

A member of the research team demonstrated to each participant how to properly complete each exercise and evaluated the participant for correct form, prior to the first WBV session. Each session included a customized PowerPoint program that reminded participants of the exercise order, proper form and rest/exercise timing. The WBV platform uses a chip reader system with customized cards for each participant that sets the specific parameters for the WBV_{Ex} and records the session allowing the researcher to monitor compliance and timing of each session. Additionally, a member of the research team was present to assist participants during each session. An example of all exercise can be found in appendix 3

<u>Exercises</u>

1. *Plank*: performed on the WBV platform with the participant's forearms on the platform and feet off the platform. The vibration was set to six hertz and the arms were placed at an amplitude of three millimeters for participants in the WBV_{Ex} group.
2. *Isometric Squat:* performed on the WBV platform. The vibration was set to 15 hertz and the feet were placed for an amplitude of three millimeters for participants in the WBV_{Ex}

group. During the squat participants were asked to lightly grip the handrail of the WBV platform for safety but not use it to support their weight.

3. *Side plank:* performed on the WBV platform, with the participant's arm located across the middle of the platform. The vibration was set to six hertz for participants in the WBV_{Ex} group.
4. *Bridge:* performed on the WBV platform, with the participant's feet on the platform. The vibration was set to 15 hertz and the feet were placed for an amplitude of three millimeters for participants in the WBV_{Ex} group.
5. *Modified v-up:* performed on the WBV platform, with the participants buttocks centered on the center of the platform. Participants completed the modified v-up with their feet off the ground and their back past the handle bars of the WBV platform. The vibration was set to six hertz for participants in the WBV_{Ex} group.
6. B*ack extension:* performed on the WBV platform, with the participant's hands on the WBV platform. The vibration was set to 15 hertz and the hands were placed for an amplitude of three millimeters for participants in the WBV_{Ex} group.

Measurements

Visual Analog Scale

The VAS has been previously validated as a measure of pain.[163] VAS was used to evaluate each participants low back pain prior to, at the four kilometer mark, immediately following, one day following and two days following the foot march (Figure 5). Each participant marked a line along a 100 millimeter line that spans from the word "no pain" to "worst pain imaginable" to indicate their pain level. A MCID of 35mm for acute and 18mm for chronic back pain has been determined to correspond to a patients perception of pain control across a range of ages and genders.[127] Therefore these numbers will be used to evaluate clinic significant changes in low back pain. A sample of the VAS has been attached in appendix 4.

Algometry

An algometer (Force Ten^{TM} FDS Digital Force Gage, Wagner Instruments, Greenwich CT) was used to measure muscle soreness in the low-back. Low back muscle soreness was evaluated prior to, immediately following, one and two days following the foot march (Figure 5). Participant's low back, three centimeters lateral to the fourth vertebrate of the lumbar spine was bilaterally marked for algometer application, prior to the start of the foot march. Lateral to the fourth vertebrae of the lumbar spine was selected as it has been shown to have a high reproducibility for muscle soreness of the erector spinae.[128]

Following a practice round, pressure threshold was measured three times on each side of the body and the average was taken. The participant was instructed to say "stop" when they felt pain or discomfort from application of the algometer. The algometer was pushed into the participant's lower back at a consent rate of $1kgcm^{-2}s^{-2}$. This rate was chosen to increase reliability between trials.[130] Only one researcher measured algometry throughout the study to improve consistence of the measurements.

Performance

A stopwatch was used to time foot march performance. Time was recorded halfway through the foot march and at the completion of eight kilometer foot march (Figure 5). The timer was not stopped for water breaks or rest breaks.

Muscle Activation

Muscle activation of the rectus abdominis and erector spinae was measured using Delsys Trigno Avanti sensors (Delsys Inc., Natick, MA). Muscle activation was evaluated prior to, at the four kilometer mark, immediately following, one day following and two days following the foot march (Figure 5). The EMG sensors for the rectus abdominis were placed three centimeters lateral to the umbilicus[60,136] to reduce interference with the MOLLE belt. The EMG sensor for the erector spinae was placed at three centimeters lateral to the first vertebrae of the lumber spine was used for this study.[60,133,164]

Each area was shaved with a disposable razor to remove all hair, debrided with alcohol and gauze until the skin was pink indicating that the skin was adequately debrided. Following the debridement the area was left uncovered for five minutes to dry. Sensors were then placed on the skin with double sided adhesive tape by the same researcher throughout the study. Sensors were additionally secured by cover roll (BSN medical, Hamburg, Germany) to reduce movement throughout the foot march.

Post-processing of EMG data was completed using EMGworks analysis (Delsys Inc., Natick, MA, USA). EMG signals were onboard filtered using a Butterworth filter, bandwidth 20-450 hertz. Raw EMG data from each muscle high passed filtered using a 4^{th} order butterworth filter to reduce noise from cardiac muscle. [165,166] Finally a root mean squared (125ms) amplitude analysis was completed on each signal, normalized to the first kilometer of each foot march.

Muscle Damage and Inflammation

Blood serum markers CK and IL-6 were collected to assess muscle damage and inflammation. Blood was drawn prior to, immediately following, one day and two days post-foot march (Figure 5). Blood was drawn from the antecubital vein using a 21 gauge safety-lok needle (BD vacutainer, Becton, Dickinson and Company, NJ, USA). Members of the research team certified by the Auburn University phlebotomy training course collected one vial of blood into a 10 milliliter serum blood collection tube (BD Vacutainer, Becton, Dickinson and Company, NJ, USA). Blood samples were placed in a refrigerator until all collections were completed for that session. Samples were centrifuged at 3,500xg for 10 minutes at room temperature. Serum was extracted from the collection tube and frozen at -80 degrees (Kendra Laboratory Products Company, Ashville, NC, USA) until analysis. Enzyme Linked Immunosorbent Assays (ELISA) were used to analyze IL-6 (Invitrogen, ThermoFisher Scientific, Asheville, NC, CV: 9.8%) according to the manufacturer's instructions. All IL-6 samples were analyzed in duplicates, with pre-, post-, one day and two days post-foot march samples on the same plate. Plates were analyzed using a multispectral spectrophotometer (BioTek Eon, Winooski, VT, USA). Creatine kinase was analyzed at a CLIA-certified laboratory in the Auburn-Opelika AL area.

Posture and Heart Rate

Posture and heart rate were measured using a Zephyr bioharness (Medtronics, Minneapolis, MN, USA). Both posture and heart rate were evaluated prior to, at the four kilometer mark, immediately following, one day following and two days following the foot march (Figure 5). The Zephyr Bioharness has been shown to be a valid measure of both posture and heart rate, with a strong relationship ($r > 0.990$) to a standardize tilt table and a strong relationship ($r > 0.940$) to a polar heart rate monitor.[167] The Zephyr bioharness strap was placed on the participant's chest with the Zephyr under the participants left arm pit, level with the xiphoid process of the sternum. The Zephyr bioharness was place upright so that a participant in an upright position was indicated by zero degrees, 1 to 180 was forward flexion and -1 to -180 was extension. Posture was measure prior to, at the four kilometer mark and immediately following the foot march.

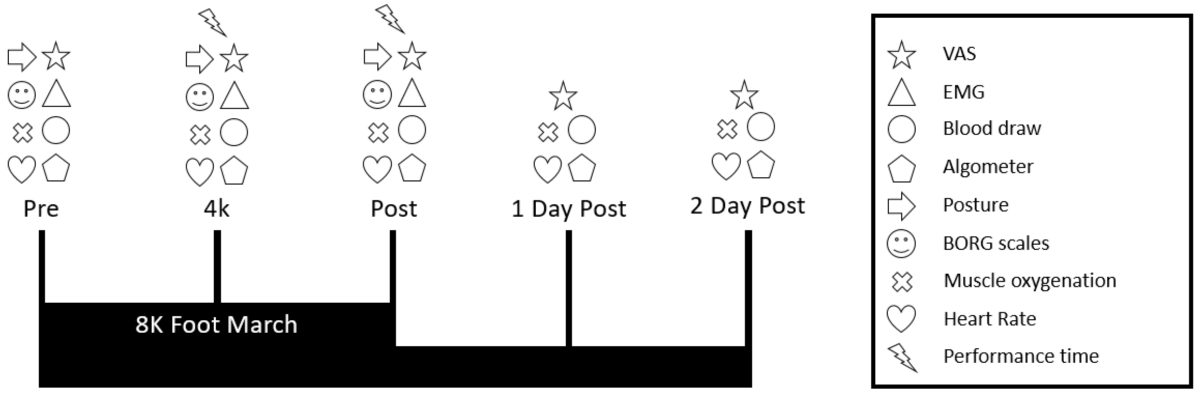
Rate of Perceived Exertion

The participants rate of perceived exertion was measured using the BORG scale, which has been validated in young healthy adults.[168] The BORG scale was measured prior to, halfway through, and immediately following each foot march (Figure 5). Participants were asked to rate their perceived exertion on the BORG scale, spanning from six (No exertion) to 20 (Maximal exertion). A sample of the BORG Scale has been attached in appendix 5.

Muscle Oxygenation

Muscle oxygenation was measure using a Humon Hex monitor (Dynometrics, Cambridge, MA, USA), which has been validated against the near-infrared spectroscopy.[146] The Humon Hex was placed on the muscle belly of the rectus femoris. Muscle oxygenation was recorded prior to, at the four kilometer mark, immediately following, one day following and two days following the foot march (Figure 5).

Figure 5: Measurement study design



Legend: This figure illustrates the time points for measurements taken during each foot march

Statistical Analysis

All statistical analyses were complete using R statistical software[169] and R studio.[170] Additionally several R programming packages: dplyr,[171] lme4,[172] reshape2,[173] emmeans,[174] ggplot2,[175] psych[176] were used for analyses. Descriptive statistics was calculated for each groups and is presented as means ± standard deviation. Mixed effects models were used to evaluate the difference between WBV_{Ex}, Ex and control groups for low back pain, performance time, muscle damage, posture, heart rate, muscle oxygenation, and RPE. Correlations between variables were evaluated prior to analyses and no significant correlation were found between variable, therefore univariate mixed effects models were completed. Treatment group, measurement time point, and foot march were all included as fixed effects for the mixed effects model. Subject identification number, interaction of measurement time point and subject identification number, and the interaction of foot march and subject identification number were all included as random effects for the mixed effects model. Assumption testing of normality and homogeneity were evaluated prior to analysis of each mixed effects model. The VAS, EMG muscle activation, CK and IL-6 were not normally distributed and were therefore log transformed for analysis. An *a priori* alpha level of 0.05 was used to determine significant results.

Cohen's *d* effect sizes were calculated for each outcome variable across foot march (foot march one versus foot march two) for each treatment group. A Cohen's *d* calculation for effect sizes from mixed effects models was utilized (equation 2).[177] Effect sizes were classified as small ($d < 0.2$), medium ($0.2 < d < 0.5$) or large ($d < 0.8$).[178]

$$d = \frac{mean\ difference}{\sqrt{var\ intercept + var\ slope + var\ residual}}$$

Equation 2: Cohen's d equation used for mixed effects models. Abbreviations: variance (var), Cohen's *d* (*d*)

Chapter 4 Effects of Whole Body Vibration on Low Back Pain During and Following a Foot March

Introduction

Foot marches are ubiquitous within military units as they are vital to transporting mission essential equipment across the operational environment. Throughout history, service members have been asked to carry weapons and equipment on their person.[2] Service members were rarely asked to carry equipment exceeding 30 pounds prior to the Civil War.[2] The increasing complexity of modern day warfare requires warfighters to routinely carry equipment exceeding 100 lbs.[5]

Load carriage demands on today's warfighter have lead to increased non-combat musculoskeletal injuries (MSI).[5] Load carriage is the second leading cause of MSI in infantry units.[6] Service members carrying weights exceeding 30 pounds are 50-60 percent more likely to sustain an MSI.[5] During load carriage the majority of weight is carried on the service members back. Thus it is not surprising that back MSI are among the most frequently observed foot march injury.[5,8,48] Researchers and military commands have investigated various equipment and carrying techniques for military foot marches in an effort to reduce these MSI. Among these techniques are doublepacks, high carrying loads, and low carrying loads.[10,11,49,69] Double packs distribute the load around the trunk in order to maintain a more normal center of mass which may decrease overall back pain.[10] However these packs increased hip and neck pain and decreased the range of motion which is required to complete operational tasks.[10] Distribution of weight in the ruck sack on the upper part of the back has been shown to reduce the forward lean of service members as compared to placing the weight low on the back.[11] However, placing the weight high on the back when marching on uneven terrains has been shown to be destabilizing.[11] Thus, placement of the weight high on the back may reduce risk of MSI when marching on even terrain, while placing the weight lower on the back may reduce MSI when marching on uneven terrain.[49,69] Weight distribution and rucksack design may help to mitigate some of the discomfort service members experience during foot marching. However, the incidence of back MSI resulting from load carriage remains high. There is a clear need for more effective interventions to reduce MSI from load carriage.

Whole body vibration (WBV) is a low frequency, low amplitude, mechanical vibration exercise that has been shown to produce physiological changes in both bone and muscle. WBV is used as an alternative or additive therapy for exercise in populations that are unable to complete traditional physical exercise. WBV has been shown to stimulate osteocytes to decrease bone breakdown and increase bone formation.[179,180] WBV has also been shown to influence neuromuscular potentiation through the tonic vibration reflex.[81] Specifically, WBV has been used to increase bone mineral density,[13,14] balance,[13] and strength in elderly patients,[13,14] reduce obesity,[16] and the rehabilitate anterior cruciate ligament[17] and chronic ankle instability.[18-20]

WBV training has been used to reduce low back pain and overall disability in patients with chronic low back pain. WBV with or without a combination of core exercises increased core muscle activity and proprioception in patients with chronic low back pain[21-26,32] and in healthy patients.[112] Thus, the addition of WBV to a core exercise program may strengthen core muscles and increase core muscle activation during foot marching to help maintain posture and reduce low back stress. The purpose of this study was to determine if a WBV exercise intervention reduced low back pain in healthy, active individuals during and after an eight kilometer weighted military foot march.

Methods

A three by five repeated measures randomized experimental control trial was used to determine the effects of a WBV intervention on low back pain during and after a weighted eight kilometer foot march. Participants were required to be 19 – 35 years of age, healthy, physically active adults. Interested participants completed a health questionnaire to determine eligibility and were consented by a member of the research team. This study was approved by the Auburn University Internal Review Board.

Participants were randomly divided in one of three groups; WBV and core exercise (WBV_{Ex}), exercise (Ex) or control. All participants completed two, self-paced, eight kilometer weighted foot marches separated by four weeks. During each foot march participants carried a 35 pound Modular Lightweight Load-Carrying Equipment (MOLLE) around an indoor track. Each MOLLE was fitted and packed by a US Army Lieutenant Colonel Infantry Soldier to simulate military standard packing conditions. Following the first foot march (FM1) and a one-week recovery period, the WBV_{Ex} and Ex groups completed an intervention of core exercise training (with WBV or without WBV depending on group assignment) for a period of three weeks. For the core exercise training participants performed three sets, for 30 seconds each, of planks, side-planks, isometric squats, v-ups, bridges, and back extensions three times a week (Figure 6). All core exercises, regardless of group, were completed on a side-alternating WBV platform (Galileo Med L Novotec Medical, Pforzheim, Germany) as illustrated in Figure 6. The WBV platform was turned on only during core exercises for the WBV_{Ex} group. During isometric squatting and bridge exercises the WBV frequency was set to 15 hertz with an amplitude of three millimeters (peak acceleration = 1.36g). This frequency with a low amplitude has been shown to increase muscle contraction of the erector spinae and rectus abdominis compared to lower frequencies in patients with chronic low back pain.[112] The remaining exercises (planks, side-planks, v-up, and back extensions) were completed at a frequency of six hertz, due to the proximity of the participants head to the platform (peak acceleration = 0.21g). All exercises were completed in bare feet and reported according to WBV reporting guidelines.[181] For safety participants were asked to lightly grip the WBV platform handrail, but not support their weight, during the isometric squat. The control group completed their normal activity for three weeks.

Figure 6. Core exercise training program

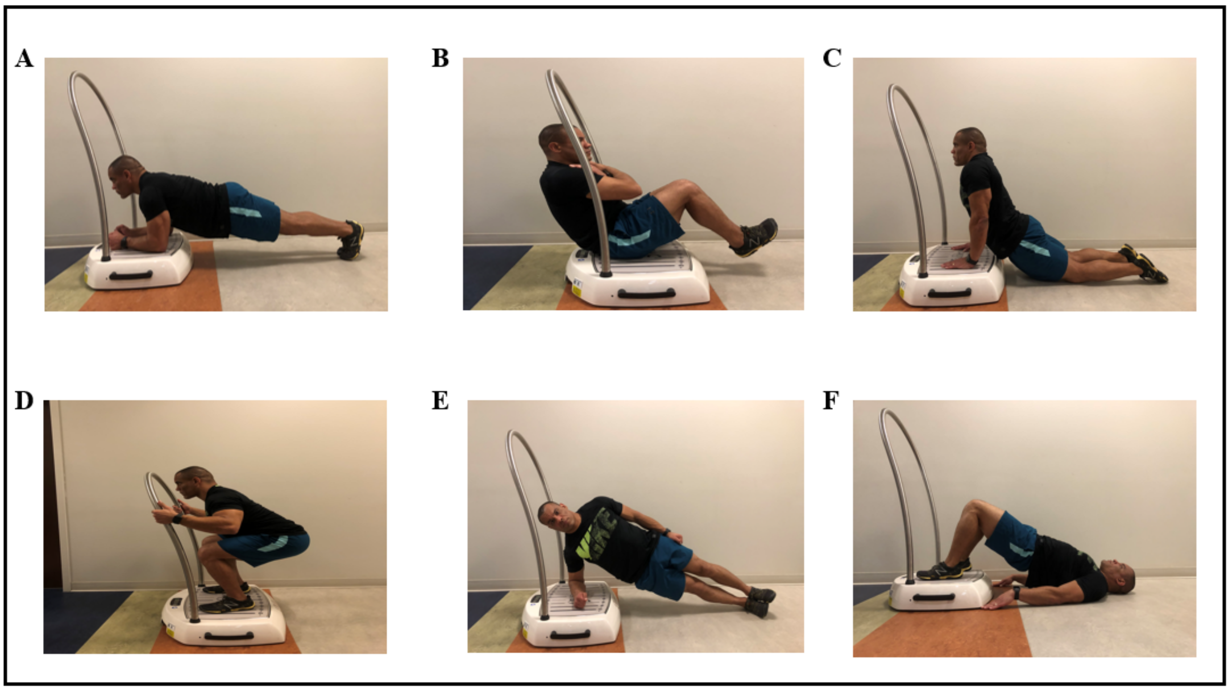


Figure #. Core training program for WBV_{Ex} and Ex groups.

Legend: (A) plank, (B) v-up, (C) back extension, (D) squat, (E) side plank, (F) bridge

Pain and Muscle Soreness Assessment

A 100 millimeter visual analog scale (VAS) was used to evaluate low back pain pre-foot march, during (at four kilometers), post-foot march, one day and two days following each eight kilometer foot march. For each measurement participants were presented a new VAS ranging from 'no pain' to 'worst pain imaginable'. Participants were instructed to place a horizontal mark indicating their low back pain along the scale at each time point. Additionally, an algometer (Force Ten™ FDS Digital Force Gage, Wagner Instruments, Greenwich CT, USA) was used to evaluate low back muscle soreness. Bilateral marks for application of the algometer prior to the foot march were placed on each participants back, three centimeters lateral to the fourth vertebrae of the lumbar spine.[128] Algometer measurements were taken pre- and post-foot march and one and two days following the foot march. Participants were instructed to tell the researcher when they felt pain or discomfort from the pressure of the algometer. One practice trial was completed on each side of the back, followed by three alternating measurements. The average score for each time point was used for analysis.

Muscle Activation Assessment

Electromyography (EMG) was used to evaluate the effects of WBV and core exercises on muscle activation access an eight kilometer foot march. EMG data was collected via four wireless Tringo Avanti Sensor (Delsys Inc., Natick, MA, USA). Surface EMG was selected as it has been shown to be a non-invasive, reliable measure of muscle activation.[133] Sensors were preset to a sampling rate of 2000 hertz for all data collections. Sensors were placed bilaterally on the erector spinae and rectus abdominis to determine the effect of WBV and core exercise training on core muscle activation. Each area was shaved and abraded using a razor, alcohol and gauze pads and left exposed to dry for five minutes prior to placement of sensors. One researcher placed sensors on each participant to reduce interrater reliability. EMG sensors were placed on the rectus abdominis three centimeters lateral to the umbilicus, parallel to the muscle fibers.[60,136] Additionally EMG sensors were placed on the erector spinae three centimeters lateral to first vertebra of the lumbar spinae, parallel to the muscle fibers.[60,133,164]

Muscle activation was recorded during the first, middle, and last kilometer of the foot march. A Butterworth on board filter with a bandwidth of 20-450 hertz was used during collection. All raw EMG signals were high-pass filtered at 30hz to reduce noise from cardiac muscle activity.[165,166] A root mean squared (125ms) amplitude analysis normalized to the first kilometer of each foot march was then completed on each EMG signal.

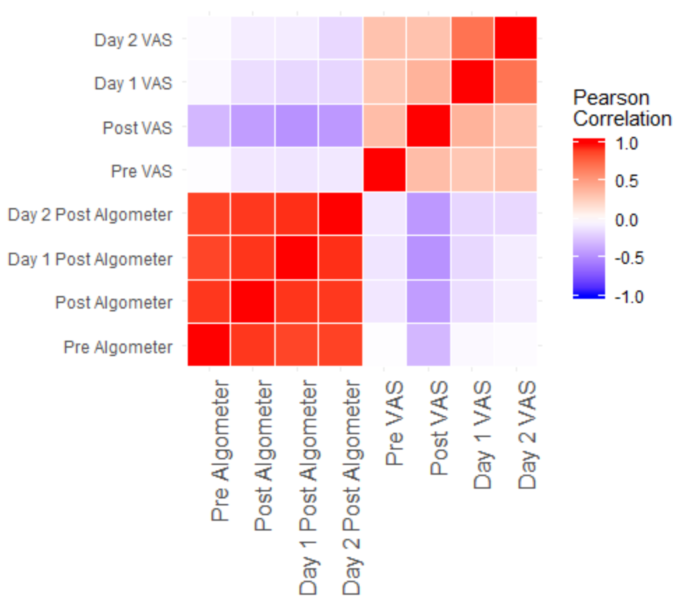
Posture Assessment

Posture was evaluated during the eight kilometer foot march to evaluate the effects of WBV and core exercise on proprioception during a weighted military foot march. A Zephyr bioharness (Medtronics, Minneapolis, MN, USA) was placed across the participant's chest with the zephyr device located under the participants left arm. Posture was evaluated at the first, middle and last kilometer of the foot march. A posture of zero degrees indicated that the participants was standing in the vertical position, positive 90 degrees indicated that participant was in the prone position, and negative 90 degrees indicated that the participant was in the supine position.[182]

Statistical Analysis

Statistical analyses were completed using R statistical software[169] and R studio.[170] R programming packages used included; dplyr,[171] lme4,[172] reshape2,[173] emmeans,[174] ggplot2,[175] psych.[176] Mixed effects models were used to evaluate the effect of WBV_{Ex} on low back pain, pain pressure threshold of the low back, posture and muscle activation of the erector spinae and of the rectus abdominis. Correlations between all variables were evaluated. There was no significant correlations between VAS and algometry for any of the measurement time points, therefore univariate models were used for both VAS and algometer results (Figure 7). Fixed effects for the model included treatment group (WBV_{Ex}, Ex, Control), measurement time point (Pre, 4 kilometers, Post, Day 1 Post, Day 2 Post), and foot march (FM1, FM2). Random effects for the model included the subject identification number, interaction of measurement time point and subject identification number, and the interaction of foot march and subject identification number. Post hoc analyses were used to test significant interactions and main effects. Additionally Cohen's d effect sizes[177] were calculated for each variable and classified as small ($d < 0.2$), medium ($0.2 < d < 0.5$) and large ($d < 0.8$).[178] Assumptions of normality of residuals and homogeneity of residuals were evaluated using residuals of the mixed effects model. Assumptions of normality were violated for EMG muscle activation and the VAS. Both variables were log transformed to meet the assumption of normality. An *a priori* alpha level of 0.05 was used to determine significant results.

Figure 7. Heat map of correlations between VAS and algometer



Legend: Correlations values are represented as Pearson correlations (r)

Results

Forty-one participants volunteered to complete this study. Two participants were dropped from the study, one was unable to complete all aspects of the study due a lack of time and one due to a foot injury. Thus, thirty-nine participants (female = 17, male = 22) completed all aspects of the study and were used for analysis. Demographics for the thirty-nine participants are located in Table 1.

Table 1. Summary of descriptive statistics

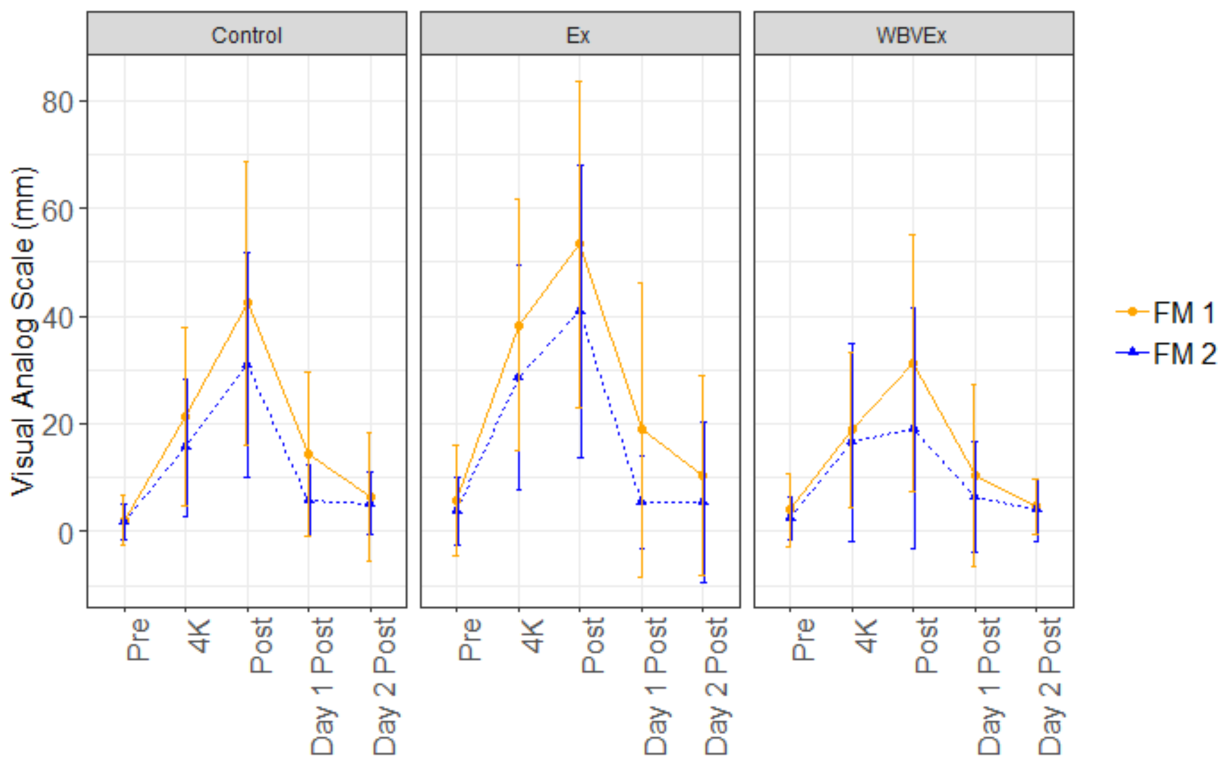
Group	Age (yrs)	Height (cm)	Weight (kg)
WBV_{Ex}	23.385 ± 3.906	173.804 ± 7.477	75.822 ± 12.169
Ex	22.846 ± 1.625	167.435 ± 9.161	69.932 ± 12.166
Control	25.615 ± 5.440	172.427 ± 7.794	83.269 ± 15.107*

Legend: All data are presented as mean ± standard deviation. Abbreviations: years old (yrs), centimeters (cm), kilograms (kg), whole body vibration and core exercise group (WBV_{Ex}), exercise group (Ex), *Significant difference between weight of the Ex and control group ($p < 0.05$).

Visual Analog Scale

There was no significant interaction between treatment group, foot march number and measurement time points for the VAS (F = 0.863, p = 0.549). Additionally, there was no interaction between foot march and treatment group (F = 0.409, p = 0.667), foot march and measurement time point (F = 2.038, p = 0.092), or treatment group and measurement time point (F = 1.525, p = 0.153). There was a main effect of foot march (F = 10.974, p = 0.002) and measurement time point (F = 70.796, p < 0.001) on the VAS, but no main effect of group (F = 0.444, p = 0.645). Regardless of foot march, the VAS was significantly elevated four kilometers into the foot march (t = 4.638, p < 0.001), immediately following the foot march (t = 15.501, p < 0.001), and one day (t = 4.899, p < 0.001) and two days following the foot march (t = 0.044, p = 0.044) as compared to prior to the foot march. VAS scores were also significantly elevated immediately following the foot march (t = 2.986, p = 0.003) as compared to the VAS scores at the four kilometer midpoint of the foot march and one day following the foot march (t = 10.640, p < 0.001), indicating that low back pain continued to increase throughout the foot march but decrease the following day. There was a significant difference in VAS scores between day one and day two following the foot march (t = -2.852, p = 0.004), indicating that low back pain continued to decrease two days after the foot march. Lastly VAS scores were significantly lower during FM2 as compared to FM1 (t = -2.701, p = 0.007) regardless of treatment group or measurement time point (Figure 8.). In summary, low back pain measured by the VAS increased throughout the foot march and remained elevated following the foot march for two days. There was no difference between treatment groups for low back pain, however completing a second foot march did decrease low back pain.

Figure 8. Summary of VAS differences between groups



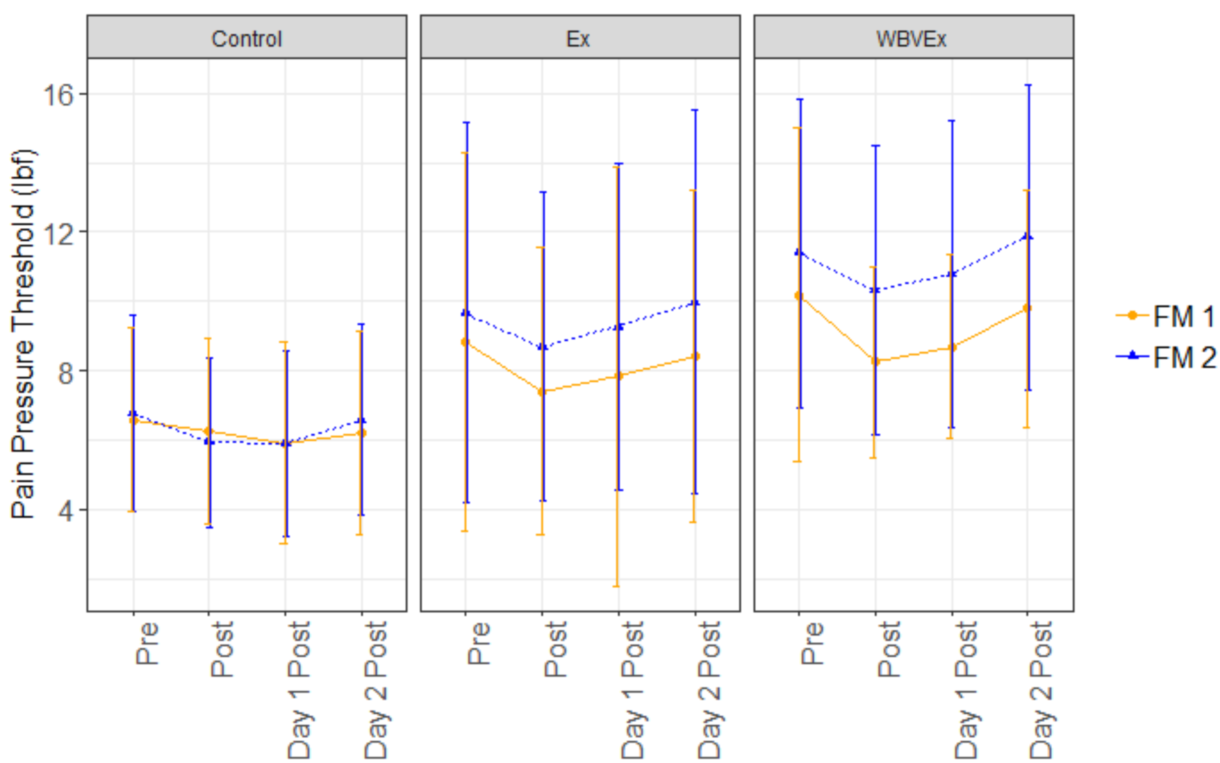
Legend: Data presented as means ± standard deviations. Abbreviations: whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

Algometer

One participant's algometer measurements were removed prior to analysis because the participant refused to acknowledge the stimulus was painful until after the study. Additionally, readings between the two sides were average for further analysis due to a strong correlation between left and right algometer readings ($r = 0.970$). No significant interaction was found between foot march, treatment group and measurement time point ($F = 0.839$, $p = 0.543$). A significant interaction was indicated between foot march and treatment group for the algometer ($F = 4.152$, $p = 0.024$), however no significant interactions were found between measurement time point and treatment group ($F = 1.057$, $p = 0.393$), or foot march and measurement time point ($F = 1.525$, $p = 0.212$). Post hoc analysis indicated a significant difference between algometer measurements between the WBV_{Ex} and control group during FM1($t = -2.290$, $p = 0.027$) and FM2 ($t = -3.791$, $p < 0.001$). No difference was found between the WBV_{Ex} and Ex groups for FM1 ($t = -1.625$, $p = 0.113$) or FM2 ($t = -1.987$, $p = 0.054$). No difference was found between the Ex and control groups for FM1 ($t = -0.619$, $p = 0.540$) or FM2 ($t = -1.729$, $p = 0.092$).

There were main effects of measurement time point ($F = 9.535$, $p < 0.001$), foot march ($F = 15.391$, $p < 0.001$) and group ($F = 4.856$, $p = 0.014$). Regardless of foot march and group algometer measurements were significantly decreased immediately following the foot march, ($t = -3.725$, $p < 0.001$) and one day following the foot march ($t = -3.027$, $p = 0.003$) as compared to prior to the foot march indicating a decrease in pressure pain threshold. However, there was no significant difference between algometer measurements two days following the foot march as compared to prior to the foot march ($t = -0.394$, $p = 0.694$). Additionally, there was no difference between immediately following the foot march and one day following the foot march ($t = 0.698$, p = 0.486) indicating that pain pressure threshold remained constant for 24 hours following the foot marches. Regardless of treatment group and measurement time point, algometer scores were significantly increased across time points for FM2 as compared to FM1, indicating an increase in pressure pain threshold as compared to the FM1 ($t = 5.991$, $p < 0.001$). Regardless of foot marches and measurement time points, the WBV_{Ex} had a significantly increased algometer readings as compared to the control group ($t = -3.097$, $p = 0.003$), but no difference as compared to the Ex group ($t = -1.842$, $p = 0.074$). No difference was found between the Ex and control group ($t = 1.192$, $p = 0.240$). In summary, pain pressure threshold of the low back decreased following the foot march last for one day after the foot march. Additionally, pain pressure threshold increase following the second foot regardless of treatment group.

Figure 9. Summary of algometer differences between groups



Legend: Data presented as means ± standard deviations. Abbreviations: whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

Table 2. VAS and algometer effect sizes

Immediately Post Foot March

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
VAS	WBV_{Ex}	-12.077	-0.723	Large
	Ex	-12.692	-0.760	Large
	Control	-11.462	-0.686	Large
Algometer	WBV_{Ex}	2.078	0.592	Medium
	Ex	1.388	0.396	Medium
	Control	-0.331	-0.094	Small

1 Day Post Foot March

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
VAS	WBV_{Ex}	-3.923	-0.235	Small
	Ex	-13.380	-0.801	Large
	Control	-8.538	-0.511	Medium
Algometer	WBV_{Ex}	2.109	0.601	Large
	Ex	2.188	0.623	Large
	Control	-0.002	-0.001	Small

2 Days Post Foot March

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
VAS	WBV_{Ex}	-0.312	-0.187	Small
	Ex	-4.846	-0.290	Small
	Control	-1.241	-0.074	Small
Algometer	WBV_{Ex}	2.262	0.645	Large
	Ex	1.530	0.436	Medium
	Control	0.145	0.041	Small

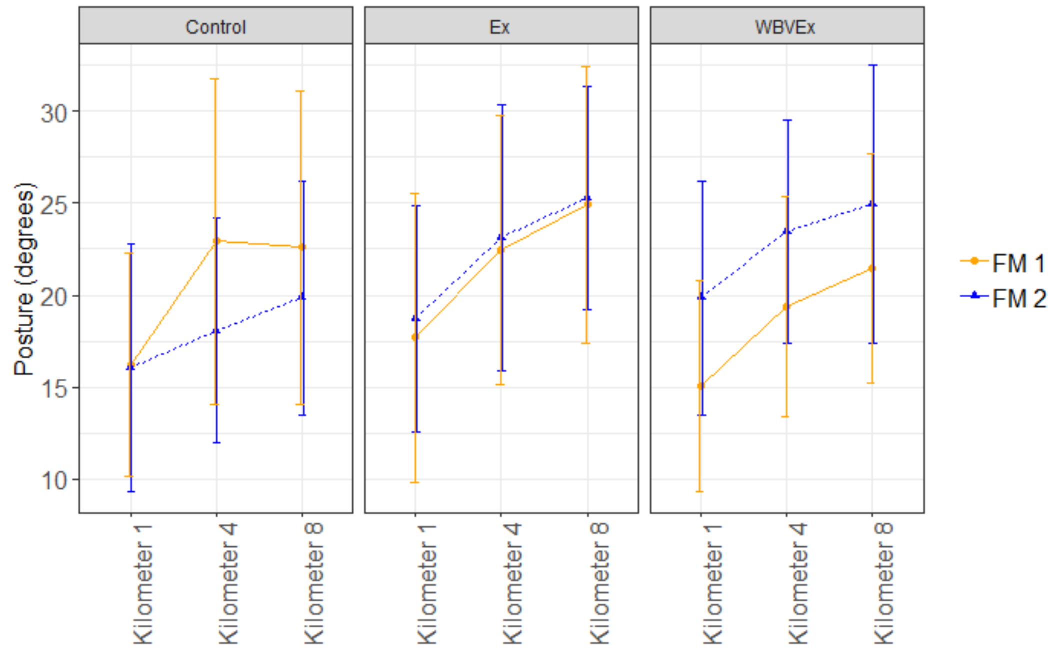
Legend: Effect sizes are presented as Cohen's *d* effect sizes. Abbreviations: Whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), visual analog scale (VAS), Foot March 1 (FM1), Foot March 2 (FM2)

Posture

There was no interaction between foot march, measurement time point, and treatment group for posture ($F = 1.447$, $p = 0.227$). A significant interaction was indicated between foot march and treatment group for posture ($F = 3.635$, $p = 0.036$), however there was no interaction between foot march and measurement time point ($F = 3.017$, $p = 0.056$) and treatment group and measurement time point ($F = 0.625$, $p = 0.646$). Post hoc analysis indicated no significant difference in posture between groups during FM1. However, during FM2 the WBV_{Ex} group was had a significant increase in trunk flexion posture as compared to the control group ($t = -2.025$, $p = 0.049$). The WBV_{Ex} also had an increased in trunk flexion posture during FM2 as compared to FM1 ($t = 3.565$, $p < 0.001$). The control group had a decrease in trunk flexion posture during FM2 as compared to FM1 ($t = -2.175$, $p = 0.031$).

There was a main effect of measurement time point on posture ($F = 76.238$, $p < 0.001$), but no main effect was found for foot march ($F = 0.471$, $p = 0.497$) or group ($F = 0.478$, $p = 0.478$). Regardless of group and foot march, posture was significantly increased during the middle forth kilometer($t = 5.932$, $p < 0.001$) and the last kilometer ($t = 8.090$, $p < 0.001$) indicating an increase in trunk flexion compared to the first kilometer of the foot march. Additionally, there was a significant increase trunk flexion posture during the last kilometer as compared to the fourth kilometer ($t = -2.180$, $p = 0.030$). In summary, during Fm2, the WBV_{Ex} group had a significant increase in trunk flexion as compared to the control group. Additionally, regardless of treatment group and foot march number, there was an increase in trunk flexion throughout the foot march.

Figure 10. Summary of posture differences between groups



Legend: Data presented as means ± standard deviations. Abbreviations: whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

<u>EMG</u>

There was no significant interaction between foot march, measurement time point, treatment group and individual muscle (F = 0.482, p = 0.926). No interactions were found between foot march, measurement time point and group (F = 0.540, p = 0.707), foot march, measurement time point, and muscle (F = 0.872, p = 0.515), foot march, treatment group and muscle (F = 0.979, p = 0.438), or treatment group, muscle and measurement time point (F = 0.301, p = 0.989). A significant interaction was indicated between foot march and individual muscle for muscle activation (F = 3.563, p = 0.014) however, no interactions were found between foot march and time point measurement (F = 0.533, p = 0.587), foot march and treatment group (F = 0.575, p = 0.681), measurement time point and muscle (F = 0.288, p =

0.943), or treatment group and muscle ($F = 0.385$, $p = 0.889$). Post hoc analysis indicated that the left rectus abdominis was significantly more activated during FM1 and FM2 as compared to the right erector spinae (FM1: $t = -2.592$, $p = 0.009$, FM2: $t = -2.865$, $p = 0.004$) and left erector spinae (FM1: $t = -2.145$, $p = 0.032$, FM 2: $t = -3.008$, $p = 0.002$). The left rectus abdominis was not different than the right rectus abdominis during FM1 ($t = 0.569$, $p = 0.570$), however it was significantly increased during the FM2 ($t = -3.137$, $p = 0.002$). Additionally, the left rectus abdominis had increased muscle activation during the FM2 compared to FM1 ($t = -2.551$, $p < 0.010$). Similarly, the right rectus abdominis had an increase activation during FM1 as compared to the right erector spinae ($t = -3.134$, $p < 0.002$) and left erector spinae ($t = -2.687$, $p < 0.007$), however no difference was found during FM2. Additionally, there was no difference in activation during FM2 as compared to FM1 for the right rectus abdominis ($t = -1.126$, $p = 0.260$). The left erector spinae was not significantly different from the right erector spinae for FM1 ($t = 1.876$, $p = 0.673$) or FM2 ($t = 0.155$, $p = 0.876$). Additionally, the left erector spinae was not significantly different between foot marches ($t = 1.876$, $p = 0.061$), however the right erector spinae was significantly increase during FM2 ($t = 2.323$, $p = 0.020$).

There was a main effect of individual muscles on muscle activation ($F = 2.978$, $p = 0.031$). No main effect was found for foot march ($F = 2.724$, $p = 0.108$), measurement time point ($F = 0.665$, $p = 0.515$), and treatment group ($F = 1.050$, $p = 0.357$). Regardless of foot march, measurement time point and treatment group, the left rectus abdominis was significantly more activated then both the left ($t = -3.586$, $p < 0.001$) and right erector spinae ($t = -3.806$, $p < 0.001$). The right rectus abdominis had increased activation as compared to the right erector spinae ($t = -1.980$, $p = 0.048$). However, there was no difference between the left and right rectus abdominis ($t = 1.772$, $p = 0.077$) or left and right erector spinae ($t = -0.195$, $p = 0.846$). In summary muscle activation of the left and right rectus abdominis was greater than the left and right erector spinae, regardless of foot march and group. Additionally, the left rectus abdominis muscle activation was greater than the right rectus abdominis during the second foot march.

Table 3. Posture and muscle activation effect sizes

First Kilometer

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
Posture	WBV_{Ex}	4.769	1.359	Large
	Ex	1.000	0.285	Small
	Control	-0.154	-0.044	Small
Left Erector Spinae	WBV_{Ex}	2.864	0.097	Small
	Ex	5.633	1.191	Small
	Control	3.010	0.102	Small
Right Erector Spinae	WBV_{Ex}	3.640	0.124	Small
	Ex	-1.741	-0.059	Small
	Control	7.607	0.258	Small
Left Rectus Abdominis	WBV_{Ex}	-2.343	-0.080	Small
	Ex	-0.476	-0.162	Small
	Control	-3.239	-0.110	Small
Right Rectus Abdominis	WBV_{Ex}	-2.385	-0.081	Small
	Ex	-2.172	-0.074	Small
	Control	3.177	0.108	Small

Fourth Kilometer

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
Posture	WBV_{Ex}	4.077	1.162	Large
	Ex	0.692	0.197	Small
	Control	-4.846	-1.381	Large

Left Erector Spinae	WBV_{Ex}	19.974	0.678	Large
	Ex	24.182	0.821	Large
	Control	10.652	0.362	Medium
Right Erector Spinae	WBV_{Ex}	6.705	0.228	Small
	Ex	7.927	0.269	Small
	Control	5.814	0.197	Small
Left Rectus Abdominis	WBV_{Ex}	4.377	0.149	Small
	Ex	17.087	0.580	Medium
	Control	-15.209	-0.516	Medium
Right Rectus Abdominis	WBV_{Ex}	0.795	0.027	Small
	Ex	-17.359	-0.589	Medium
	Control	0.516	0.018	Small

Eighth Kilometer

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
Posture	WBV_{Ex}	3.462	0.986	Large
	Ex	0.03866	0.011	Small
	Control	-2.75	-0.784	Large
Left Erector Spinae	WBV_{Ex}	1.604	0.054	Small
	Ex	1.245	0.042	Small
	Control	-0.897	-0.030	Small
Right Erector Spinae	WBV_{Ex}	7.688	0.261	Small
	Ex	9.535	0.324	Medium
	Control	-2.589	-0.088	Small
Left Rectus Abdominis	WBV_{Ex}	6.31	0.214	Small
	Ex	44.318	1.5	Large
	Control	-7.011	-0.238	Small

Right Rectus Abdominis	WBV_{Ex}	1.333	0.045	Small
	Ex	-16.118	-0.547	Medium
	Control	4.361	0.148	Small

Legend: Effect sizes are presented as Cohen's *d* effect sizes. Abbreviations: Whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), Foot March 1 (FM1), Foot March 2 (FM2). Posture as measured by a zephyr bioharness

Discussion

This project examined how a WBV intervention with a core exercise training program influenced posture, muscle activation, and low back pain during and after an eight kilometer weighted foot march. On average, participants had an increase in low back pain throughout each foot march that remained elevated for two days as compared to prior to the foot march. Low back pain across the groups peaked immediately following the foot march and continued to decrease across the two follow-up days.

Overall, low back pain was significantly decreased during the second foot march as compared to the first foot march. A large effect size for low back pain was seen for each group immediately following the foot march from FM1 to FM2 (Table 2). These effect sizes indicate that completing two foot marches within a month may decrease overall low back pain during the second weighted eight kilometer foot march. This recommendation is in line with current literature showing that two foot marches a month increase foot march performance.[40] However, previous research did not evaluate if a reduction in low back pain was a factor in the improved performance.[40] There was an average decrease in the VAS of approximately 12 millimeters (indicating decreased pain) when comparing the end of FM1 and the end of FM2 regardless of group. Our results were statistically significant but likely not clinically significant. Current literature indicates that an minimal clinical difference (MCID) for acute low back pain is 35 millimeters.[127]

No statistical difference was found between groups for low back pain as measured by the VAS. WBV has been used as a means to treat participants with chronic low back pain.[21-27] To the authors knowledge this is the first study that has used WBV to prevent or reduce low back pain in otherwise healthy participants. It is possible that a lack of difference in low back pain between groups may have been due to an overall low level of low back pain generated in participants after the weighted foot march. All participants that completed the study were free from current low back pain or injuries prior to the study. An increase of 38 millimeters and 27 millimeters on the VAS, indicating an increase in pain, were found immediately following FM1 and FM2, respectively. Approximately half of the participants during the first foot march did not have a clinically significant increase in low back pain (MCID 35 millimeters[127]). Additionally, during the second foot march more than half of participants did not have a clinically significant increase in low back pain. Thus, it is possible that the lack of induced low back pain did not enable us to detect differences between the intervention groups.

Pain pressure threshold measured with an algometer also decreased immediately following each foot march as compared to prior the foot march. However, contrary to the VAS results there was no difference in pain pressure threshold one or two days following the foot march. The VAS and algometry have previously been shown to be correlated,[183] however we found no significant correlation between the two measurements. These two measurements assess a different component of back pain. The VAS may be a better assessment of low back pain at low levels. There was a medium effect of WBV_{Ex} group (d = 0.592) and Ex group (d = 0.396) on pain pressure threshold immediately following the foot march comparing FM1 to FM2. Whereas only a small effect (d = -0.094) was found in the control group. This difference in effect sizes may indicate a clinically relevant increase in the amount of pressure needed to produce muscle pain following the foot march for WBV_{Ex} and Ex.

An increase in overall trunk stiffness due to co-activation of the trunk flexors and extensors is typically seen during load carriage.[4] The results of this study indicate that while both muscles were activated during the foot march, there was an increase in muscle activation of the rectus abdominis as compared to the erector spinae. These results are in line with previous research indicating an increase in rectus abdominis activation even in load carriage with light weight.[66,67] Load carriage of ten percent of body weight has been shown to increase core muscle activation by 20 to 30 percent,[66,67] and load carriage of 15 percent of body weight can increase core muscle activation by 54 to 105 percent.[66,67] Increases in core muscle activation are due to the need to counterbalance the shift in center of mass resulting from a posterior load on the back. Alternatively, the erector spinae has been shown to require a larger amount of load carriage weight before increases in muscle activation are seen. Load carriage weights from 63.9 to 103.6 pounds (29 to 47 kilograms) have been shown to increase erector spinae activation.[52,65] Carrying weights of less than 15 percent of body weight has been shown to decrease muscle activation of the erector spinae.[52,65] During the current study, participants carried a 35 pounds (15.9 kilograms) rucksack, which was on average 21 percent of the participants bodyweight. This weight was chosen because it is the weight commonly used for entry level foot march training. Our participants were untrained, novice foot marchers and we did not want to put them at risk for injury. The load carriage weight used may not have been heavy enough to provide a substantial increase in erector spinae activation. Unloaded muscle activation patterns were not assessed during this study. Additionally, our results revealed a significant increase in the left rectus abdominis activation as compared to the right rectus abdominis during FM2 across all groups. Previous literature has shown an increase in muscle activation of the right rectus abdominis as compared to the left.[66,67] Bilateral differences in muscle activation patterns can increase the risk of MSI or pain. In our study participants walked left around an indoor track which may have caused an increase in muscle activation on the left side as compared to the right.

The WBV intervention and/or exercise training did not increase rectus abdominis or erector spinae activation during FM2 as compared to the FM1. These results are contrary to previous literature showing that WBV increased core muscle activation in patients with chronic low back pain. Patients with chronic low back pain often have reduced core muscle activation which negatively effects their back pain levels.[83] The current study was completed by healthy participants free of chronic low back pain; therefore they may not have had a reduction in core muscle activation prior to the intervention. Previous research indicating increases in core muscle activation in healthy subjects has been limited to immediately following whole body vibration.[31] In our study participants did not complete the foot march immediately following or during the same days as the WBV training.

WBV has been effective in increasing proprioception in patients with chronic low back pain.[22,32] Participants in this study were not instructed on proper posture for a weighted military foot march. There were no postural difference between groups for FM1, however the WBV_{Ex} group did have an increase in trunk flexion posture for FM2 as compared to the control group. It is possible that a combination of WBV and core exercise training was able to strengthen the core musculature to allow participants to safely increase forward flexion posture without increasing back pain. This increase in trunk flexion posture would allow the participant to reposition their center of mass forward to increase forward momentum and possibly provide increases in speed or performance during the foot march as increases in trunk flexion have been associated with faster walking speeds.[184] It is important to note that increase in forward flexion have been shown to increase the amount of compressive force on the low back as compared to a fully erect or supine position.[51] However, the increase in forward flexion for the WBV_{Ex} groups did not increase low back pain but actually decreased the amount of low back pain seen in the participants at four kilometers and at the end of the foot march.

The WBV and core exercise intervention was utilized based on previous WBV interventions focused on patients with chronic low back pain.[21,22,24,25,27] Additionally, while a range of frequencies 3-34 hertz have been utilized,[21-25,27] frequency settings were based off previous research indicating that 15 hertz vibration increase muscle activation of the core muscles greater than lower frequencies.[112] [112] A frequency of six hertz was used for exercises that brought the head closer to the platform (plank) so participants could safely complete these exercises. While low frequencies have been successful in reducing chronic low back pain,[21-25,27] higher frequencies have been used to induce greater muscle activation in healthy populations.[185] It is possible that the chosen frequencies were not high enough to induce the increased muscle activation required for improving core strength.

Limitations

The weight and distance chosen for this study were based on load carriage weights and distances used during initial entry training for Soldiers. We chose to mimic conditions used for that soldiers with no previous experience and to reduce the chance of injury to our inexperienced participants. The low weights and relatively short distance compared to weights and distances typically completed by active duty service members may have reduced the amount of low back pain seen during this study. This lack of low back pain may have reduced the outcomes found. WBV treatment parameters were based off previous literature for patients with chronic low back pain. It is possible that frequency parameters and treatment length were insufficient to induce significant changes in the healthy population. Lastly, this foot march was completed on an indoor track to reduce the effect of environmental conditions and outside confounding variables that may have impacted this study, and likely did not mimic real conditions such as uneven terrain and inclines may have on low back pain during foot marches.

Conclusion

Military eight kilometer weighted foot marches significantly increase low back pain in novice participants. This low back pain remains elevated for a minimum of two days following the eight kilometer weighted foot march. Completing two foot marches within a month significantly decreases the amount of low back pain that is seen in novice participants in the second foot march. A combination of WBV and core exercise training or core exercise training alone may have provided a clinically relevant increase in pain pressure threshold following the foot march. Additionally, a combination of WBV and core exercise training safely increases trunk flexion, which may have future implications on performance time. Lastly while we did not find increases in core muscle activation between groups, we did find an overall increase in rectus abdominis activation as compared to erector spinae activation. This information may provide information for recommendations on muscle strengthening in future foot march research. Future research with WBV and core exercise training should be completed with higher weights and longer distances. Additionally, future research may focus on service members that already are experiencing low back pain or MSI as a results of military foot marches.

Chapter 5: The Effects of Whole Body Vibration on Military Foot March Performance

Introduction

Military foot marches have historically been used for moving equipment and personnel to complete mission objectives. Even with the development of armored transportation equipment and unmanned aerial surveillance equipment, this mode of transportation is still vital in modern day warfare. Load carriage weight has significantly increased following the American Civil War to a level where it now exceeds 100 pounds during the war in Afghanistan.[2-4]

An inability for a warfighter to adapt to the musculoskeletal requirements to complete these the heavily loaded foot marches may decrease overall mission success and impair unit performance following the foot march. A 30 minute load carriage of greater than 40 kilograms has been shown to decrease a service members vigilance to random tactile clues.[186] Load carriage has also been shown to significantly decrease both marksmanship accuracy and precision.[187] Additionally, service members have reported that load carriage decreases their mobility, marksmanship, grenade throwing, general duties and overall attention-to-task.[188]

Research has investigated how to improve foot march performance and recovery following weighted foot marches. Investigations into specific resistance training and endurance training programs has found that a combination upper body resistance training and endurance training improved foot march performance.[41,73,74] Upper body resistance training, including the core, is equally important due to a need to stabilize the load carriage weight. Completing two or four foot marches in a month increased foot march performance compared to zero or one foot march foot march a month.[40] Additionally, military training used to train new service members such as basic combat training (BCT) and Initial Entry Training (IET), have been evaluated to determine if these programs increase foot march performance.[189] However, only BCT has been shown to be effective in increasing foot march performance in the Australian army.[189]

Whole body vibration (WBV) training is a low frequency, low amplitude mechanical stimulus that has been used to increase performance and recovery in athletes and untrained subjects. WBV has been shown to increase strength,[33] balance,[84] flexibility,[84] countermovement jump performance [35] and sprinting speed.[36] WBV training has been shown to increase running economy in marathon runners.[38] Additionally WBV has been shown to increase activation of the vastus lateralis, tibialis anterior and gastrocnemius muscles.[86] However core muscle activation during walking gait following WBV has not been investigated. WBV has also been used to improve recovery following intense physical activity, decrease the decrements of muscular strength common after eccentric exercise,[97] and decrease overall muscle soreness by 36-46.03%[97] and perceived pain by 22-61%.[101] To the authors knowledge no studies have evaluated the effect of WBV training on weighted foot march performance or recovery. Therefore, the purpose of this study was to determine how WBV training effects performance and recovery from an eight kilometer weighted foot march.

Methods

A three by five repeated measures randomized control trial was used to evaluate the effects of WBV and exercises on performance and recovery from an eight kilometer foot march. Participants completed a health questionnaire to determine eligibility for this study and were required to be healthy, at least 19 years of age and completing regular exercise. Participants meeting these requirements that volunteered for the study completed an informed consent. This study and its procedures were approved by the Auburn University Review Board.

Study participants were randomly place into a WBV and exercise group (WBV_{Ex}), exercise (Ex) or control group. Participants completed two eight kilometer foot marches separated by a period of four weeks. For each foot march the participants carried a 35 pound Modular Lightweight Load-Carrying Equipment (MOLLE), fitted and packed by a US Army Lieutenant Colonel Infantry Soldier. Foot Marches were self-paced by the participants; however participants were asked to complete the foot march as fast as they could safely navigate the eight kilometer march. Participants were not allowed to run during the foot march, as forced marches are only completed in a small minority of military foot marches due to their detrimental effects on unit effectiveness.[6] Following the completion of the first eight kilometer foot march, participants in the WBV +Ex and exercise group had a one week washout period prior to the beginning an exercise intervention. The control group completed their normal activity for four week.

Core Exercise Intervention

Participants in the WBV_{Ex} and Ex groups completed three weeks of core exercise training three times per week. Each exercise was completed three times for 30 seconds on a side-alternating WBV platform, regardless of exercise group. The WBV was only turned on during the WBV_{Ex} intervention. The core exercise intervention consisted on planks, side-planks, isometric squats, v-ups, bridges and back extensions. Figure 6 illustrates each exercise including the participant's body placement on the WBV platform. The WBV platform was set to 15 hertz with an amplitude of three millimeters (peak acceleration = 1.36g) for the isometric squat and bridge, as this has been previously shown to increase core muscle activation. The WBV platform was set to six hertz with an amplitude of three millimeters (peak acceleration = 0.21g) for planks, side-planks, v-ups and back extensions to reduce vibration to the head. All exercises were completed in bare feet and were reported following WBV reporting guidelines.[181] To increase participants safety during the intervention participants were asked to lightly grip the WBV platform handrail, but not support their weight, during the isometric squat.

Performance Assessment

Performance was measured as the amount of time taken to complete the eight kilometer weighted foot march as measured by a standard stop watch (Athletic Works digital stopwatch, Bentonville, AR, USA). Participants were asked to complete the foot march as fast as they could safely navigate the eight kilometers without running. Participants were allowed to rest and drink water ad libitum. The performance time was the full time, start to finish, including any breaks taken by the participant.

Rate of Perceived Exertion (RPE) Assessment

The BORG scale was used to evaluate the affect core exercise training and WBV have on rate of perceived exertion (RPE) during a weighted foot march. The BORG scale has previously been validated in young healthy adults.[148] RPE was measured before, during (at the four kilometer point) and after the foot march. At each time point participants were instructed to RPE level from six (no exertion) to 20 (maximal exertion) on the BORG scale.

Heart Rate Assessment

Heart rate was evaluated using a Zephyr bioharness (Medtronics, Minneapolis, MN, USA) The Zephyr bioharness strap was fitted around the participant's upper chest with the Zephyr sensor placed under the participants left arm, level with the zyphoid process of the sternum. Heart rate was capture pre-foot march, during (four kilometers), post-foot march, and one day and two days following the foot march.

Muscle Oxygenation Assessment

Muscle oxygenation was measured using a Humon Hex monitor (Dynometrics, Cambridge, MA, USA), which has been previously validated using near-infrared spectroscopy.[146] The Humon Hex was placed on the muscle belly of the participants right rectus femoris. Muscle oxygenation was captured pre-foot march, during (four kilometers), post, one day and two days following the foot march.

Muscle Damage and Inflammation Assessment

Biomarkers of creatine kinase (CK) and interlukin-6 (IL-6) were used to evaluate the effect of the WBV intervention and core exercise training on muscle damage during a weighted foot march and during recovery from a foot march. Blood was taken from the anticubical vein by a member of the research team via a 21-gauge needle (BD Vacutainer Safety-Lok Blood Collection Set, Becton, Dickinson and Company, Franklin Lakes, NJ USA). A single 10 ml serum blood collection tube (BD Vacutainer Serum Blood Collection Tube, Becton, Dickinson and Company, Franklin Lakes, NJ USA) was used to collect the participant's blood. Samples were centrifuged following collection at 3,500xg for 20 minutes to separate serum. Tubes that did not display a clear separation of serum were centrifuged for an additional ten minutes until a clear separation was present. Serum was pipetted from the blood tube and frozen in three milliliter cryogenic vials (Neptune cryogenic vials, VWR, Radnor, PA, USA) at -80 degrees (ThermoFisher Scientific, Asheville, NC, USA) until analysis. IL-6 was measured using an Enzyme Linked Immunosorbent Assay (Invitrogen, ThermoFisher Scientific, Asheville, NC, USA, CV: 9.8%). All samples were analyzed in duplicate, with all of a participant's samples on a single plate. Two IL-6 samples were outside of the normal physiological range and were removed from analysis. Serum samples were analyzed by the CLIA-certified laboratory at the local Auburn-Opelika AL hospital for CK. Two participants were unable to give blood samples and were not included in analysis.

Statistical Analysis

R statistical software[169] and R studio[170] was used to complete all statistical analyses. R programming packages used for analysis included; dplyr,[171] lme4,[172] reshape2,[173] emmeans,[174] ggplot2,[175] psych.[176] Mixed effects models were used to evaluate the effect of WBV_{Ex} on performance time, heart rate, muscle oxygenation, rate of perceived exertion, IL-6, and CK. Treatment group (WBV_{Ex}, Ex, Control), measurement time point (Pre, 4 kilometers, Post, Day 1 Post, Day 2 Post) and foot march (FM1, FM2) were used as fixed effects for each model. Subject identification number, interaction of measurement time point and subject identification number and the interaction of foot march and subject identification number were included as random effects for each model. Model interactions and main effects were analyzed using post hoc analyses. Assumption testing of normality of residuals and homogeneity of residuals were evaluated using mixed model residuals. Assumptions of normality were violated for CK and IL-6, therefore both variables were log transformed. An *a prior* alpha level of 0.05 was set to determine significant results. Cohen's *d* effect sizes were calculated for each variable and classified as small ($d < 0.2$), medium ($0.2 < d < 0.5$) and large ($d < 0.8$).[178]

Results

Forty-one participants volunteered for this study. Two participants dropped out of the study, one due to an inability to complete all aspects of the study due a lack of time and one due to a foot injury. Thirty-nine participants (female = 17, male = 22) completed all aspects of the study and were used for analysis. Demographics for all thirty-nine participants are located in Table 1. Two participants were unable to give blood and therefore only 37 samples were analyzed for CK and IL-6.

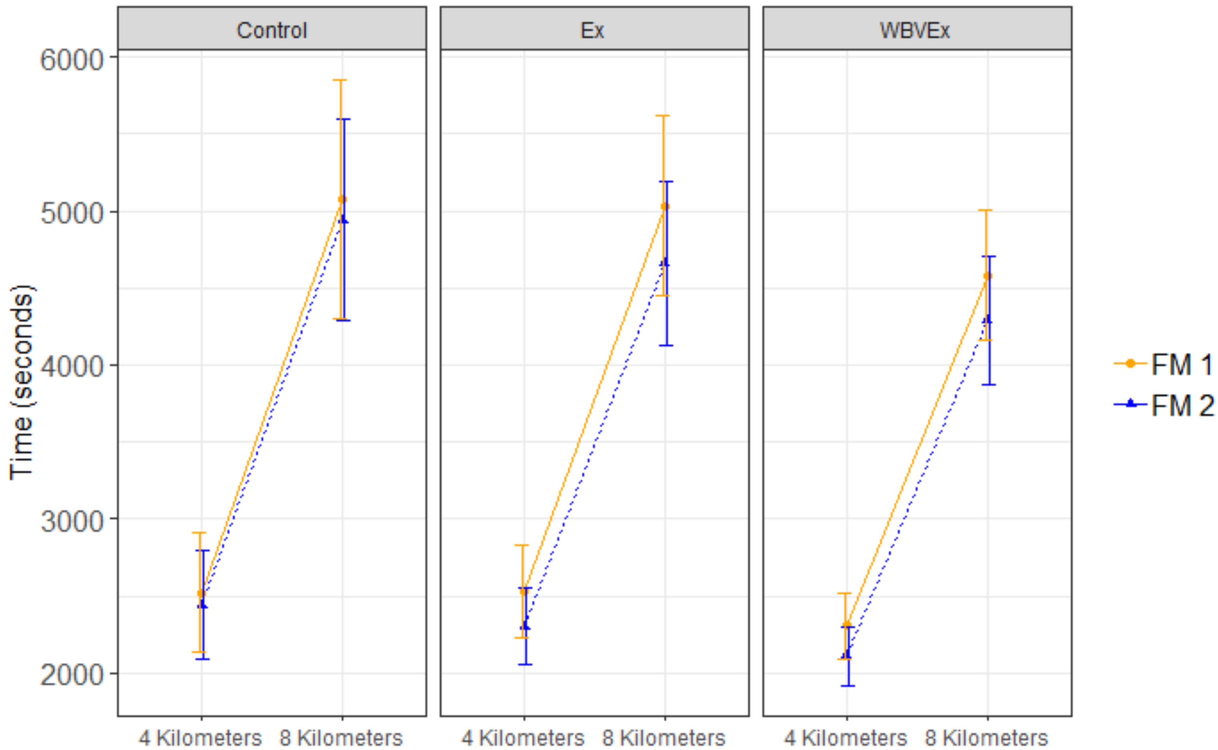
<u>Performance</u>

There was no significant interaction between foot march number, treatment group, and measurement time point (F = 0.908, p = 0.412). Significant interactions were found between foot march and treatment groups (F = 3.893, p = 0.029), foot march and measurement time point (F = 12.160, p = 0.001), and treatment group and measurement time point (F = 3.608, p = 0.037). WBV_{Ex} group was significantly faster completing the foot march compared to the Ex (t = 2.390, p = 0.021) and control groups (t = 3.327, p = 0.001), regardless of foot march. No difference was found between the Ex and control group (t = -0.937, p = 0.354). There was no difference in performance between any of the groups at the fourth kilometer mark. There was no significant difference between the WBV_{Ex} and control group for FM1 (t = 0.982, p = 0.328) or FM2 (t =

1.359, $p = 0.176$) at any measurement time point. There was no significant difference between the WBV_{Ex} and Ex group for Fm1 ($t = 0.935$, $p = 0.351$) or Fm2 ($t = 0.776$, $p = 0.439$). Additionally, there was no significant differences between the Ex group and control group for Fm1 ($t = 0.047$, $p = 0.963$) or Fm2 ($t = 0.583$, $p = 0.561$). Lastly, FM2 was significantly faster than FM1 for all groups, both at the four kilometer mark ($t = -3.465$, $p < 0.001$) and eight kilometer time point ($t = -5.474$, $p < 0.001$).

There were main effects of foot march ($F = 56.332$, $p < 0.001$) and treatment group ($F = 3.517$, $p = 0.040$). Regardless of group and measurement time point (fourth kilometer and eighth kilometer), there was no significant difference between Fm1 and FM2 ($t = -1.052$, $p = 0.295$). Time was also not significantly difference between the WBV_{Ex} and Ex ($t = 1.217$, $p = 0.225$) or control groups ($t = 1.665$, $p = 0.098$) and no differences were found between the Ex and control groups ($t = -0.448$, $p = 0.655$). In summary, FM2 was significantly faster than FM1, however treatment group did not significantly improve performance.

Figure 11. Summary of performance differences between groups



Legend: Data presented as means ± standard deviations. Abbreviations: whole body vibration and core exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

Heart Rate

There was no significant interaction between foot march, measurement time point and group for heart rate (F = 1.217, p = 0.293). There was a significant interaction between the treatment group and measurement time point on heart rate (F = 5.123, p < 0.001). There was no interaction between foot march and measurement time point (F = 0.903, p = 0.464) or foot march and treatment group (F = 1.962, p = 0.155). Heart rate was significantly higher in the WBV_{Ex} group as compared to the control group at four kilometers (t = -3.378, p = 0.001) and at the end of the foot march (t = -3.749, p < 0.001), but no difference was found one day (t = 0.953, p = 0.344) or two days following the foot marches (t = -0.104, p = 0.917). Heart rate was also significantly higher in the Ex group as compared to the control group at four kilometers (t = -

2.038, p = 0.045) and at the end of the foot march (t = -3.145, p = 0.002). but no difference were found a one day (t = 0.367, p = 0.714) or two days following the foot marches (t = 0.560, p = 0.576). There was no difference in heart rate between WBV_{Ex} group and Ex group for any measurement time point.

A main effect of measurement time point was found for heart rate (F = 422.807, p < 0.001). No main effects were found for foot march number (F = 1.605, p = 0.213) or treatment group (F = 1.507, p = 0.235). Post hoc analyses indicated that heart rate was significantly elevated at four kilometers (t = 22.320, p < 0.001) and immediately following the foot march (t = 27.340, p < 0.001) as compared to prior to the foot march. Heart rate was significantly increased immediately following the foot march as compared to the fourth kilometer (t = 4.924, p < 0.001), indicating that heart rate continued to rise throughout the foot march. Heart rate was significantly decreased the first (t = -5.130, p < 0.001) and second (t = -5.280, p < 0.001) day following the foot march as compared to prior to the foot march. There was no difference in heart rate between the two days (t = -0.186, p = 0.852). In summary, heart rate was increased during the eight kilometer foot march, peaking at the completion of the foot march. Heart rate was significantly higher in the $WBV_{Ex\ and}$ Ex groups during and following the foot march.

Muscle Oxygenation

There was no significant interaction between foot march, measurement time point, and treatment group (F = 0.295, p = 0.967). There was a significant interaction between the treatment group and measurement time point for muscle oxygenation (F = 3.556, p < 0.001). No interactions were found between foot march and measurement time point (F = 1.153, p = 0.334) or foot march and group (F = 0.215, p = 0.808). Regardless of FM1 or FM2 muscle oxygenation of the rectus femoris was significantly elevated prior to the foot march in the WBV_{Ex} ($t = -2.455$, $p = 0.017$) and control group ($t = 2.148$, $p = 0.030$) as compared to the Ex group. Muscle oxygenation was significantly elevated the day following the foot marches in the WBV_{Ex} ($t = -4.489$, $p < 0.001$) and control group ($t = 2.456$, $p = 0.017$) as compared to the Ex group. Additionally, muscle oxygenation was significantly elevated two days after the foot march in the WBV_{Ex} group as compared to the Ex ($t = -2.031$, $p = 0.046$) and control group ($t = -2.132$, $p = 0.036$). However, there were no differences between any group at four kilometers or at the completion of the foot march.

A main effect of measurement time point was found for muscle oxygenation ($F = 45.969$, $p < 0.001$). No main effects were found for foot march ($F = 0.081$, $p = 0.777$) or treatment group ($F = 2.918$, $p = 0.068$). Regardless of foot march or group muscle oxygenation was significantly increased at four kilometers ($t = 7.180$, $p < 0.001$) and immediately following the foot march ($t = 8.341$, $p < 0.001$) as compared to prior to the foot march. Muscle oxygenation was also significantly increased immediately following the foot march as compared to the fourth kilometer ($t = 4.618$, $p < 0.001$) indicating that muscle oxygenation continued to rise throughout the foot march. Muscle oxygenation was significantly decreased one day following the foot march as compared to prior to the foot march ($t = -2.691$, $p = 0.007$). However, there was no difference in muscle oxygenation between one and two days following the foot march ($t = -0.107$, $p = 0.915$). In summary, muscle oxygenation was increased during the eight kilometer foot march, peaking at the completion of the foot march. Muscle oxygenation during the foot march was not influence by treatment group or the completion of two foot marches.

RPE

No interaction was found between foot march, treatment groups or measurement time points for RPE ($F = 1.203$, $p = 0.317$). Additionally, there were no interactions between foot march and measurement time point ($F = 1.113$, $p = 0.334$), foot march and treatment group ($F = 0.160$, $p = 0.853$), or treatment group and time point measurements ($F = 0.353$, $p = 0.841$) for RPE. A main effect was found for measurement time point for RPE ($F = 266.526$, $p < 0.001$). No main effect was found for foot march ($F = 0.742$, $p = 0.395$) and treatment group ($F = 0.600$, $p = 0.554$). RPE was significantly increased at four kilometers ($t = 20.400$, $p < 0.001$) and immediately following the foot march ($t = 19.000$, $p < 0.001$) as compared to prior to the foot march. RPE was also significantly elevated immediately following the foot march as compared to the fourth kilometer ($t = 7.634$, $p < 0.001$) indicating that RPE continued to rise throughout the foot march. In summary, RPE increased during the eight kilometer foot march and was not influenced by treatment group or completing two foot marches.

Table 4. Time, heart rate, muscle oxygenation, and RPE effect sizes

Immediately Following Foot March

	Group	***Mean Difference (FM1-FM2)***	***Effect Size***	***Classification***
Time	WBV_{Ex}	-294	-0.645	Large
	Ex	-374.920	-0.822	Large
	Control	-134.540	-0.295	Small
Heart Rate	WBV_{Ex}	-5.923	-0.322	Medium
	Ex	7.846	0.426	Medium
	Control	-0.077	-0.004	Small

Muscle Oxygenation	WBV_{Ex}	-0.539	-0.036	Small
	Ex	3.667	0.245	Small
	Control	3.083	0.206	Small
Rate of Perceived Exertion	WBV_{Ex}	-0.077	-0.031	Small
	Ex	0.462	0.185	Small
	Control	-0.462	-0.185	Small

Legend: Effect sizes are presented as Cohen's *d* effect sizes. Abbreviations: Whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

Creatine Kinase

There was a main effect of time (F = 22.492, $p < 0.001$) and foot march (F = 8.707, p = 0.005) but no main effect of group on CK (F = 1.212, p = 0.304). Regardless of foot march and group, CK was significantly increased immediately following the foot march (t = 5.289, $p < 0.001$), one day following the foot march (t = 12.158, $p < 0.001$) and two days following the foot march (t = 7.545, $p < 0.001$) as compared to pre- foot march. CK peaked one day following the foot march, which was significantly increased in comparison to immediately following the foot march (t = -6.869, $p < 0.001$) and two days following the foot march (t = -4.519, $p< 0.001$). Additionally, FM1 had a significantly increased CK levels as compared to FM2 (t = -3.456, p = 0.005) regardless of group and measurement time point.

A significant interaction between foot march, treatment group and measurement time point was found for CK (F = 2.982, p = 0.010). For FM1 CK was significantly elevated following the foot march as compared to pre-foot march levels march in both the Ex group (t = 3.177, p = 0.002) and control group (t = 2.144, p = 0.035), but not in the WBV_{Ex} group (t = 1.927, p = 0.055). For all groups CK was significantly elevated one day following FM1 as compared to pre-foot march levels (WBV_{Ex}: $t = 4.712$, $p < 0.001$, Ex: $t = 7.211$, $p < 0.001$, Control: $t = 5.691$, $p < 0.001$) and immediately following the foot march. (WBV_{Ex}: $t = 2.785$, $p = 0.005$, Ex: $t = 4.034$, $p < 0.001$, Control: $t = 2.924$, $p < 0.001$). CK remained elevated two days following FM1 as compared to pre-foot march levels in the Ex ($t = 4.774$, $p < 0.001$) and control groups ($t = 5.037$, $p < 0.001$) but returned to baseline levels in the WBV_{Ex} group ($t = 1.736$, $p = 0.083$). Additionally, during FM1 CK in the control group was significantly elevated two days after the foot march as compared to the WBV_{Ex} ($t = 2.291$, $p = 0.025$) and Ex groups ($t = 2.211$, $p = 0.030$).

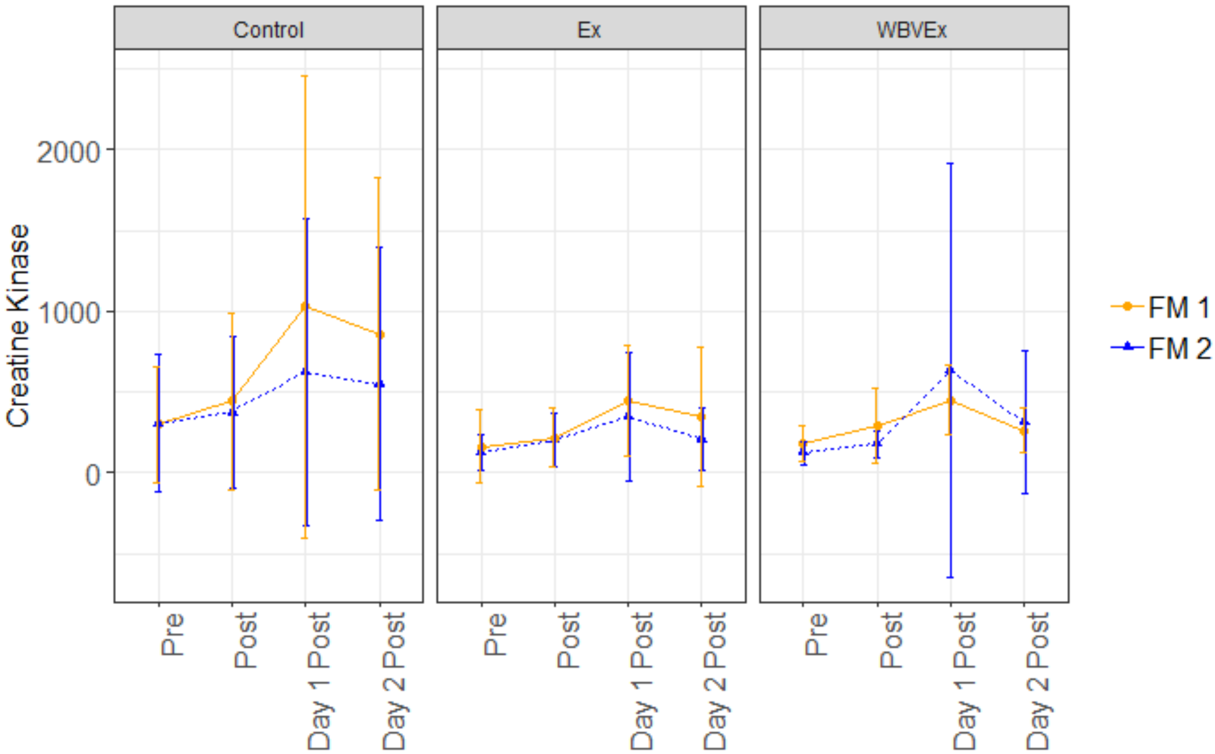
During FM2 CK was significantly elevated following the foot march as compared to pre-foot march in both the Ex group ($t = 2.769$, $p = 0.006$) and WBV_{Ex} group ($t = 2.260$, $p = 0.025$) but not in the control group ($t = 1.176$, $p = 0.240$). For all groups CK was significantly elevated one day following the first foot march as compared to prior to the foot march (WBV_{Ex}: $t = 5.520$, $p < 0.001$, Ex: $t = 5.070$, $p < 0.001$, Control: $t = 2.702$, $p = 0.007$). CK remained elevated two days following the first foot march as compared to prior to the foot march in the WBV_{Ex} ($t = 3.454$, $p < 0.001$) and Ex groups ($t = 2.561$, $p = 0.011$) but returned to baseline levels in the control group ($t = 1.594$, $p = 0.112$).

In comparison of the FM1 and FM 2 for the WBV_{Ex} group, there was a significant decrease in CK prior to FM2 as compared to FM1 ($t = -2.110$, $p = 0.036$). There was no difference between foot marches in the WBV_{Ex} group for immediately following the foot march ($t = -1.776$, $p = 0.070$), one day ($t = -1.302$, $p = 0.194$), or two days following the foot marches ($t = -0.425$, $p = 0.671$). In the Ex group there was a significant decreased in CK two days following FM2 as compared to two days following FM1 ($t = -2.036$, $p = 0.043$). There was no difference between FM1 or FM2 in the Ex group for prior to ($t = 0.177$, $p = 0.860$), immediately following ($t = -0.231$, $p = 0.817$), and one day following the foot march ($t = -1.957$, $p = 0.052$). In the control group there was a significant decrease in CK for FM2 as compared to FM1 for one day following ($t = -2.590$, $p = 0.010$) and two days following the foot march ($t = -2.931$, $p = 0.004$). There was no difference between FM1 or FM2 in the control group for prior to ($t = 0.398$, $p = 0.691$) or immediately following the foot march ($t = -0.540$, $p = 0.590$).

There was a significant interaction between foot march and measurement time point for CK ($F = 3.196$, $p = 0.027$). Regardless of group, during FM1 there was a significant increase in CK immediately following the foot march ($t = 4.179$, $p < 0.001$), one day ($t = 10.185$, $p < 0.001$) and two days following the foot march ($t = 6.711$, $p < 0.001$) as compared to prior to the foot march. During FM1 CK was increased one day following the foot march as compared to immediately following ($t = -6.006$, $p < 0.001$) and two days following the foot march ($t = -3.395$, $p < 0.001$). Regardless of group, during FM2 there was a significant increase in CK immediately following the foot march ($t = 3.594$, $p < 0.001$), one day ($t = 7.682$, $p < 0.001$), and two days following the foot march ($t = 4.377$, $p < 0.001$). Additionally, there was an increase in CK one day following FM2 as compared to immediately following the foot march ($t = -4.088$, $p < 0.001$) and two days following the foot march ($t = -3.245$, $p < 0.001$).

There was an interaction between treatment group and time point ($F = 2.790$, $p = 0.013$). Regardless of foot march, in the WBV_{Ex} group there was a significant increase in CK immediately following ($t = 2.841$, $p = 0.005$), one day following ($t = 6.942$, $p < 0.001$), and two days following the foot march ($t = 3.495$, $p < 0.001$) as compared to prior to the foot march. Additionally, in the WBV_{Ex} group there was an increase in CK one day following the foot march as compared to immediately following ($t = -4.101$, $p < 0.001$) and two days following the foot march ($t = -3.364$, $p < 0.001$). Regardless of foot march, in the Ex group there was a significant increase in CK immediately following ($t = 4.035$, $p < 0.001$), one day following ($t = 8.338$, $p < 0.001$), and two days following the foot march ($t = 4.977$, $p < 0.001$) as compared to prior to the foot march. Additionally, in the Ex group there was an increase in CK one day following the foot march as compared to immediately following ($t = -4.303$, $p < 0.001$) and two days following the foot march ($t = -3.360$, $p < 0.001$). Regardless of foot march, in the control group there was an increase in CK immediately following ($t = 2.232$, $p = 0.027$), one day following ($t = 5.695$, $p < 0.001$) and two days following the foot march ($t = 4.571$, $p < 0.001$) as compared to prior to the foot march. In the control group there was a significant increase in CK one day following the foot march as compared to immediately following the foot march ($t = -3.463$, $p < 0.001$), however there was no difference between one or two days following the foot march ($t = -1.055$, $p = 0.292$). In summary creatine kinase increased following an eight kilometer foot march, peaking at one day after the foot march. In the Ex and control groups, creatine kinase was significantly lower two days following FM2 as compared to two days following FM1. Additionally, in the control group, creatine kinase was significantly decreased one days following FM2 as compared to one days following FM1.

Figure 12. Summary of creatine kinase differences between groups



Legend: Data presented as means ± standard deviations. Abbreviations: whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

<u>IL-6</u>

There was no interaction for foot march number, measurement time point and treatment group for IL-6 (F = 1.399, p = 0.225). Additionally, there was no interaction between foot march and treatment group (F = 0.245, p = 0.784), foot march and measurement time point (F = 0.610, p = 0.610) or treatment group and measurement time point (F = 0.798, p = 0.574). There was a main effect of measurement time point (F = 18.857, p < 0.001) and foot march (F = 5.977, p = 0.021) but not main effect of group (F = 0.203, p = 0.817). Regardless of foot march and group, IL-6 was significantly elevated immediately following the foot march as compared to pre-foot march (t = -6.390, p < 0.001), one day (t = -6.186, p < 0.001) and two days following the foot march (t = -8.295, p < 0.001). There was no significant difference in IL-6 levels one day following (t = 0.288, p = 0.773) or two days following the foot march (t = -1.895, p = 0.060) as compared to pre-foot march. However, there was a significant decrease in IL-6 two days following the foot march as compared to one day following the foot march (t = -2.231, p = 0.027). Lastly regardless of group and measurement time point, IL-6 was not significantly decreased during FM2 as compared to FM1 (t = -1.955, p = 0.052). In summary, IL-6 was elevated immediately following and eight kilometer foot march. Treatment group did not influence IL-6 levels, however completing a second foot march did decrease overall IL-6.

Table 5. CK and IL-6 effect sizes

Immediately Post Foot March

	Group	***Mean Difference (FM1- FM2)***	***Effect Size***	***Classification***
Creatine Kinase	WBV_{Ex}	-0.345	-0.420	Medium
	Ex	-0.043	-0.052	Small
	Control	-0.105	-0.128	Small
Iinterleukin-6	WBV_{Ex}	-0.073	-0.056	Small
	Ex	0.080	0.061	Small
	Control	0.327	0.249	Small

One Day Post Foot March

	Group	***Mean Difference (FM1- FM2)***	***Effect Size***	***Classification***
Creatine Kinase	WBV_{Ex}	-0.253	-0.308	Medium
	Ex	-0.365	-0.445	Medium
	Control	-0.504	-0.614	Large

	Group	Mean Difference (FM1- FM2)	Effect Size	Classification
Iinterleukin-6	WBV_{Ex}	0.003	0.002	Small
	Ex	-0.627	-0.478	Medium
	Control	-0.164	-0.125	Small

Two Days Post Foot March

	Group	*Mean Difference (FM1- FM2)*	*Effect Size*	*Classification*
Creatine Kinase	WBV_{Ex}	-0.085	-0.104	Small
	Ex	-0.380	-0.462	Medium
	Control	-0.584	-0.711	Large
Iinterleukin-6	WBV_{Ex}	0.568	0.433	Medium
	Ex	0.031	0.023	Small
	Control	0.441	0.336	Medium

Legend: Effect sizes are presented as Cohen's *d* effect sizes. Abbreviations: Whole body vibration and exercise group (WBV_{Ex}), exercise group (Ex), foot march one (FM1), foot march two (FM2)

Discussion

This project examined the effects of a WBV intervention and exercise on weighted military foot march performance and recovery. Heart rate, muscle oxygenation, biomarkers and RPE were assessed. On average participants in this study improved performance on the second eight kilometer foot march as compared to FM1, regardless of treatment group. This is likely from the participants becoming more accustomed to the foot march, therefore feeling more comfortable completing the foot march faster. WBV and/or exercise did not statistically increase performance compared to the control group. However, there was a large effect of the intervention on performance for the WBV_{Ex} (d = -0.645) and Ex groups (d = -0.295) compared to a small effect for the control group (-0.295). On average in the WBV_{Ex} and Ex groups participants improved their foot march time by five and six minutes respectfully, while the control group only improved by an average of two minutes. An improvement time of five to six minutes would be operationally important in military population.

Previous literature has indicated that resistance training alone has not been sufficient in increasing foot march performance.[41,72-74] A combination of resistance training and aerobic training have been shown to increase load carriage performance.[41,73,74] This study found that resistance training with or without WBV had a large effect on decreasing performance time during military foot marches without any aerobic training. A single study[41] focused on female service members found a one minute increase in foot march performance following a resistance training only program. Two studies[73,74] focused on male service members, revealed a decrease of approximately one minute for load carriage following resistance training. Each of the previous studies[41,73,74] completed their respective training program for a total of 12 weeks and used a 3.2 kilometer foot march as compared the eight kilometer foot march used in our study. This current study found a five to six minute decrease in performance time with a WBV resistance training program of only three weeks.

The previous studies[41,73,74] have specifically focused on strengthening of the lower extremity and upper extremity with some abdominal strengthening. The current study focused specifically on strengthening of the core and trunk musculature. This focus may have increased the participant’s ability to stabilize the load (rucksack), and allow more rapid completion of the foot march. Improving weighted foot march performance can have advantages for a military unit. In an operational environment, mission success can be depended on the speed at which a unit moves towards an intended objective. Improved trunk stabilization is of greater importance during foot marches of uneven terrain or various inclinations, which are typically seen in military foot marches.

Foot March pace is determined by the commander based on mission objectives. However, the regulation pace for foot marches is 30 inches at a cadence of 106 steps per minute or three miles per hour.[6] Only two participants did not meet this regulation on their initial foot march. Of these participants, one participant in the control group did not improve their time during the second foot march; however, the participant in the Ex group did improve his/her time by 11.5 minutes, improving their pace to faster than three miles per hour. It is possible that the intervention may have a greater effect on performance in participants that have are not meeting minimum Army foot march regulations. No participants in the WBV_{Ex} group were below the recommended pace for either foot march.

Few studies have evaluated the effect of WBV on performance related outcomes during walking or running. In the current study WBV plus exercise training did not increase foot march speed greater then exercise training alone. These findings are supported by a similar study evaluating the effects of a six-week WBV training program or a strength training program on running performance.[88] While WBV did increase strength, there was no increase in running performance as compared to the strength training program.[88] A single study[38] did find overall increase in running economy at selected speeds, however the study did not evaluate performance time.

Heart rate, muscle oxygenation and RPE all increased throughout the foot march and returned to baseline following the foot march as expected. WBV and/or exercise training did not have a significant effect on any of these measures when comparing FM1 and FM2. Similar findings for RPE have been found in research evaluating the effects of resistance training on load carriage performance.[73] Heart rate was significantly elevated in the WBV_{Ex} and Ex groups immediately following the foot march as compared to the control group. This difference in beats per minute is likely related to the overall increase in performance seen during the second foot march for the WBV_{Ex} and Ex groups. WBV has been shown[106] to increase muscle oxygenation during an acute bout of WBV. However, this increase of muscle oxygenation was decreased immediately following the cessation of WBV.[106] Thus it is possible that the increase in muscle oxygenation may be limited to during WBV treatment

Recovery is often an overlooked aspect of a military training. However it is essential for a solider to be able to complete soldier related tasks within minutes of completing a foot march and continue to perform warfighter tasks as required. Regardless of group we found that CK and IL-6 were significantly lower during the second foot march as compared to the first foot march. There was no significant between group differences for any of the measurement time points during the second foot march. However, during FM2 there was an increase in CK immediately following the foot march in both the WBV_{Ex} and Ex groups, but not in the control groups. Additionally, this increase in CK lasted for two days following the foot march in the WBV_{Ex} and Ex groups but not in the control group. This difference in groups may be related to the increases in performance in the exercise and WBVex groups, as CK increases with unaccustomed exercises or exercise with increasing difficulty. The WBV_{Ex} and Ex groups increased the intensity of their performance during FM2 which may have increase their CK levels, while the control group had no difference in performance.

Our results are contrary to previous literature showing that WBV increases recovery, evaluated by a decrease in CK levels. Two similar studies have evaluated the effect of WBV on recovery following eccentric exercises.[97,101] Both studies found a decrease in delayed onset muscle soreness symptoms following the completion of eccentric exercises with WBV.[97,101] However both of these studies completed an acute treatment of WBV either before or immediately following the eccentric exercise session.[97,101] The current study evaluated the effects that a chronic training program with WBV would have on recovery. It is possible that effects of WBV on recovery are limited to the using the device immediately prior to increase neuromuscular recruitment throughout exercise. Increasing muscle fiber recruitment immediately prior to exercise may reduce exercise induced muscle damage through a reduction in myofibrillar stress.[75,97] Alternatively, WBV may also be affective as a therapeutic recovery modality to help increase blood flow following the eccentric exercise to eliminate waste.[75,101]

WBV parameters and exercises for this study were selected based on parameters previously used to reduce low back pain in chronic low back patients. Higher frequencies have been shown to increase muscle activation of the lower extremity, which may increase performance.[185] Additionally, improvements in running economy were seen following a WBV intervention with a frequency of 30 hertz.[38] It is therefore possible that greater increases in performance would have been seen with higher frequencies.

Limitations

A limitation of this study was that the foot march was completed inside on a track. A majority of foot marches completed for both training and active duty missions are completed on uneven terrain. Completing the foot march on an indoor track reduced confounding variables such as environmental conditions and outside confounding factors. Additionally, WBV intervention parameters were selected based on previous literature evaluating low back injuries. It is possible that the low frequency levels were not high enough to induce significant changed in foot march performance.

Conclusions

Completing an eight kilometer weighted foot march significantly increases heart rate, muscle oxygenation and RPE. A three-week exercise training program, with or without WBV had a large effect on increasing foot march performance. This increase in performance may be due to an increase in trunk stabilization. WBV and/or exercise training did not have an effect on recovery following an eight kilometer weighted foot march. However, completing two foot marches did have a significant effect on decreasing overall CK and Il-6 levels. Future research should evaluate the effects of WBV and/or resistance training on foot marches of uneven terrain and gradients. Additionally, future WBV intervention research should focus on high frequency levels for increasing performance.

Chapter 6: Summary and Future Directions

This study examined the effects of WBV and/or an exercise training program on low back pain, performance and recovery during and after an eight kilometer weighted foot march. Completing an eight kilometer foot march with a 35 pound ruck sack significantly increased low back pain in participants for at least two days following the foot march as expected. WBV and/or exercise training did not significantly influence low back pain during or following the eight kilometer foot march. This may be due to the moderate increase in low back pain following the foot march. WBV_{Ex} and Ex interventions did have a medium effect on pain pressure threshold of the low back muscles following FM2. This suggests that WBV and core exercises or core exercise alone could have a clinically significant effect on low back pain. Reducing low back pain in service members during and following a foot march could help a service members ability to complete foot marches, while limiting missed training days after a foot march MSI. Additionally, results of this study indicate that on average participant's rectus abdominis activation was higher as compared to erector spinae activation during the foot march. This is likely due to the use of a basic training level weight of 35 pounds, as lower load carriage weight has been shown to have a greater effect on the rectus abdominis,[66,67] whereas greater load carriage weights are required to increase erector spinae activation.[52,65]

Completing an eight kilometer weighted foot march significantly increased heart rate, muscle oxygenation and rate of perceived exertion. WBV and/or exercise did not influence these measurements. WBV and exercise as well as exercise alone did have a large effect on performance during the second foot march. On average foot march performance time was decreased by five to six minutes as compared to only two minutes for the control group. An ability to increase foot march performance time of five to six minutes could be essential to mission success. Additionally, the WBV parameters selected for this study were determined by previous interventions for patients with chronic low back pain. It is possible that utilizing a higher frequency, which has been shown to increase muscle activation,[185] may produce greater increases in performance than what was found in this study.

WBV_{Ex} also increased trunk flexion posture throughout the foot march. It is important to note that while increases in forward flexion posture have been shown to increase MSI during load carriage,[48,50] the increase in our study was not associated with an increase in low back pain. It is possible that the increase in posture may be related to increases in performance resulting from an increase in trunk stabilization. Lastly muscle damage and recovery (CK and IL-6) were significantly decreased during the second foot march as compared to the first foot march; however, WBV and/or exercise did not reduce CK or IL-6 during recovery. This finding may be due to the increase in performance during FM2 requiring an increase in activity to which the participants are unaccustomed

Future Directions

Future research should continue to focus on preventing low back pain in weighted military foot marches, as well as incorporate treatment of service members with chronic low back pain from military tasks such as foot marches. The current study had high variability in some measurements, including creatine kinase and IL-6, which may have influenced the results investigating the effects of WBV and/or core exercise training on low back pain, performance and recovery from a military foot march. Future research should focus on increasing power when investigating the effects of whole body vibration and/or core exercise training. This can be accomplished by increasing sample size, utilizing more homogenous groups, assessing precise outcome measures or providing a longer exposure to WBV and/or core exercise training. New research should be expanded for carrying heavier loads, up to and exceeding 100 pounds to incorporate weights that the military is currently using in active duty military populations. These weights have been shown to increase the risk of sustaining an MSI.[5] WBV and core exercise training may have a larger impact on foot marches eliciting large amounts of low back pain. Investigations into foot marches with heavier load carriage weights would likely also increase the amount of rectus abdominis and erector spinae activation seen during the foot march. Future research should investigate if neuromuscular adaptations from the WBV and core exercise training program would provide a quicker and more substantial increase in core muscle activation to help services members maintain their center of mass displaced by the weighted ruck sack. Additionally, future research should expanded to included foot marches of uneven terrain and gradient. These more realistic foot marches will require increased trunk stabilization and may be further influenced by increases in core muscle activation

A variety of parameters have been used across WBV intervention programs. Parameters for this study focused on improvements in low back pain, however parameters may be more successful in increasing performance. Future research expanding on this study should focus on higher frequencies that may have a larger influence on muscle activation and increasing strength and performance related outcomes.

Lastly, future research should expand into military service members already experiencing low back pain or a low back MSI as a results of military tasks such as a foot march. WBV with and without core exercise training has been effective in reducing pain in chronic low back patients. The reduction in pain is influenced by increases in core muscle activation and proprioception, which are commonly deficits chronic low back patients. WBV intervention may have a greater impact on these service members and should be investigated to determine the effect on service member MSI, pain and performance.

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Appendix 1: Relevant Muscular Anatomy

Muscle	Action	Origin	Insertion	Innervation
Rectus Abdominis	➢ Flexion of the lumbar spine[51,190] against gravity ➢ Posterior rotation of the pelvis[51,190]	➢ Pubic crest[51,190] ➢ Pubic symphysis[51,190]	➢ Costal cartilage of the fifth, sixth and seventh ribs[51,190] ➢ Xiphoid process of the sternum[51,190]	➢ Ventral rami[51,190]
External Oblique	➢ Flexion of the lumbar spine[51,190] ➢ Posterior rotation of the pelvis[51,190] ➢ Rotation of the lumbar spine to the opposite side[51,190] ➢ Lateral bending of the lumbar spine to the same side [51,190]	➢ Fifth, sixth, seventh and eighth ribs (anterior fibers) [51,190] ➢ Ninth, tenth, eleventh and twelfth ribs (lateral fibers) [51,190]	➢ Linea alba (anterior fibers) [51,190] ➢ Anterior superior iliac sine, pubic tubercle and the anterior portion of the iliac crest (lateral fibers) [51,190]	➢ Iliohypogastric[51,190] ➢ Ilioinguinal[51,190] ➢ Ventral rami[51,190]
Internal Oblique	➢ Support of the abdominal vscera[51,190] ➢ Posterior rotation of the pelvis[51,190] ➢ Flexion of the lumbar spine[51,190] ➢ Rotation of the lumbar spine to the same side[51,190] ➢ Lateral bending of the lumbar spine to the same side[51,190]	➢ Lateral two-thirds of the inguinal ligament (lower fibers) [51,190] ➢ Anterior one-third of the iliac crest (upper fibers) [51,190] ➢ Middle one-third of the iliac crest (lateral fibers) [51,190]	➢ Public crest, pectineal line (lower fibers) [51,190] ➢ Tenth, eleventh and twelfth ribs (lateral fibers) [51,190] ➢ Linea alba[51,190]	➢ Iliohypogastric [51,190] ➢ Ilioinguinal [51,190] ➢ Ventral rami[51,190]
Latissimus Dorsi	➢ Extension of the spine[51,190] ➢ Anterior rotation of the pelvis [51,190] ➢ Stabilization of the lumbar spine[51,190]	➢ Spinous processes of sixth, seventh, eighth, ninth, eleventh and twelfth vertebra of the thoracic spine [51,190]	➢ Intertubercular groove of the humerus[51,190]	➢ Thoracodorsal[51,190]

	➢ Shoulder extension[51,190] ➢ Shoulder internal rotation[51,190] ➢ Shoulder adduction[51,190] ➢ Depression of the shoulder girdle[51,190]	➢ Posterior iliac crest[51,190]		
Trapezius	➢ Retraction of scapula[51,190] ➢ Fixation of thoracic spine [51,190] ➢ Depression of scapula (lower one-third) [51,190] ➢ Upward rotation of the scapula (lower one-third) [51,190]	➢ Lower portion of the ligamentum nuchae (middle one-third) [51,190] ➢ Spinous process of the seventh cervical vertebra and the spinous processes of the first, second, third, fourth and fifth vertebra of the thoracic vertebra (middle one-third) [51,190] ➢ Spinous processes and supraspinal ligaments of the eighth, ninth, tenth, eleventh, and twelfth vertebra of the thoracic spine (lower one-third) [51,190]	➢ Acromion process [51,190] ➢ Spine of the scapula [51,190]	➢ Accessory[51,190]
Rhomboid Major	➢ Retraction of the scapula [51,190] ➢ Elevation of the scapula[51,190] ➢ Downward rotation of scapula[51,190] ➢ Fixation of thoracic spine[51,190]	➢ Spinous processes of the second, third, fourth and fifth vertebra of the thoracic spine[51,190]	➢ Vertebral border of the scapula[51,190]	➢ Dorsal scapular[51,190]
Rhomboid Minor	➢ Retraction of scapula[51,190] ➢ Elevation of scapula[51,190]	➢ Inferior portion of the ligamentum nuchae[51,190]	➢ Vertebral border of the scapula[51,190]	➢ Dorsal scapularv[51,190]

	➢ Downward rotation of scapula [51,190] ➢ Fixation of thoracic spine[51,190]	➢ Spinous process of the seventh vertebra of the cervical spine[51,190] ➢ Spinous process of the first vertebra of the thoracic vertebra[51,190]		
Erector Spinae: Iliocostalis Lumborum Thoracis and Cervicis	➢ Extension of spinal column[51,190] ➢ Lateral bending of spinal column to the same side[51,190]	➢ Crest of the sacrum; spinous processes of the lumbar and lower thoracic vertebrae; iliac crests [51,190] ➢ Sixth, seventh, eighth, ninth, eleventh and twelfth ribs[51,190]	➢ Angles of the ribs[51,190] ➢ Transverse process of the vertebra of the cervical spine[51,190]	➢ Branchs of the spinal nerves (dorsal primary divisions) [51,190]
Erector Spinae: Longissimus Thoracis Cervicis Capitis	➢ Extension of the spinal column [51,190] ➢ Head extension [51,190] ➢ Head rotation to the same side[51,190] ➢ Lateral bending of the spinal column[51,190]	➢ Transverse processes of the lumbar thoracic and lower cervical vertebrae[51,190]	➢ Transverse processes of the vertebra above the vertebra of origin[51,190] ➢ Mastoid process of the temporal bone (capitis) [51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]
Erector Spinae: Spinalis Thoacis cervicis	➢ Extension of the spinal column [51,190] ➢ Lateral bending of the spine to the same side[51,190]	➢ Spinous process of the lumbar, lower thoracic and seventh vertebra of the cervical spine[51,190]	➢ Spinous process of the upper thoracic and cervical vertebrae[51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]
Erector Spinae: Multifidus	➢ Extension of the spinal column [51,190] ➢ Rotation towards the opposite side[51,190]	➢ Posterior surface of the sacrum and the ilium[51,190] ➢ Transverse processes of the lumbar, thoracic, and lower cervical vertebrae[51,190]	➢ Spinous processes of the lumbar, thoracic and cervical vertebrae[51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]

Erector Spinae: Rotatores	➢ Extension of the spinal column[51,190] ➢ Rotation towards the opposite side[51,190]	➢ Transverse processes of the vertebrae[51,190]	➢ Base of the spinous process of the vertebra above the vertebra of origin[51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]
Erector Spinae: Interspinales	➢ Extension of the spinal column[51,190]	➢ Superior surface of the spinous processes[51,190]	➢ Inferior surface of the spinous process of the vertebra above the vertebra of origin[51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]
Erector Spinae: Semispinalis Thoracis Cervicis Capitis	➢ Extension of the spinal column[51,190] ➢ Extension of the head[51,190] ➢ Rotation of the head to the opposite side[51,190] ➢ Rotation of the vertebral column to the opposite side[51,190]	➢ Transverse processes of the thoracic vertebrae and seventh cervical vertebrae[51,190]	➢ Spinous processes of the second, third and fourth thoracic vertebrae[51,190] ➢ Occipital bone[51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]
Erector Spinae: Splenius Capitis Cervicis	➢ Extension of the head[51,190] ➢ Head rotation towards the same side[51,190]	➢ Spinous processes of the upper thoracic and the seventh vertebrae from the cervical spine ➢ Ligamentum nuchae[51,190]	➢ Occipital bone ➢ Mastoid process of the temporal bone[51,190] ➢ Transverse processes of the first, second and third vertebrae of the cervical spine[51,190]	➢ Branches of the spinal nerves (dorsal primary divisions) [51,190]
Serratus Anterior	➢ Scapular upward rotation and protraction[51,190] ➢ Scapular depression (lower fibers) [51,190] ➢ Scapular elevation (upper fibers) [51,190]	➢ Anterior portion of first, second, third, fourth, fifth, sixth, seventh, eighth and ninth ribs[51,190] ➢ Aponeuroses of intercostal muscles [51,190]	➢ Costal surfaces of the superior angle of scapula and vertebral border of scapula [51,190] ➢ Inferior angle of scapula[51,190]	➢ Long thoracic[51,190]

	➢ Fixation of the scapula to the thorax[51,190]			
Gluteus Maximus	➢ Hip extension [51,190] ➢ Hip external rotation[51,190] ➢ Hip adduction [51,190]	➢ Posterior gluteal line of ilium[51,190] ➢ Posterior sacrum[51,190] ➢ Posterior coccyx[51,190]	➢ Gluteal tuberosity femur[51,190] ➢ Iliotibial tract[51,190]	➢ Inferior gluteal[51,190]
Gluteus Medius	➢ Hip abduction[51,190] ➢ Anterior fibers[51,190] ➢ Hip flexion[51,190] ➢ Hip internal rotation[51,190] ➢ Posterior fibers[51,190] ➢ Hip extension[51,190] ➢ Hip external rotation[51,190]	➢ External surface of superior ilium[51,190] ➢ Anterior gluteal line[51,190] ➢ Gluteal aponeurosis[51,190]	➢ Greater trochanter of femur[51,190]	➢ Superior gluteal[51,190]
Gluteus Minimis	➢ Hip adduction[51,190] ➢ Hip internal rotation[51,190] ➢ Hip flexion[51,190]	➢ Lower portion of ilium[51,190] ➢ Margin of greater sciatic notch[51,190]	➢ Greater trochanter of femur[51,190]	➢ Superior gluteal[51,190]

Appendix 2: Consent Form

AUBURN UNIVERSITY
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Telephone: (334) 844-4483
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(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIES TO THIS DOCUMENT)

INFORMED CONSENT

The Effects of Whole Body Vibration on muscle soreness before and after a road march and road march performance

You are being asked to take part in a research study. This research study is voluntary, meaning you do not have to take part in it. The procedures, risk, and benefits are fully described further in the consent form. The purpose of this study is to determine how whole body vibration effects performance and muscle soreness during and after a road march. You will visit the lab for a total of two road march and four follow up days. If you are in the whole body vibration group or exercise group you will also visit the lab three times a week for three weeks. You will complete a Warrior Research Center Questionnaire to determine your eligibility to complete this study. You will be asked to complete two road marches separated by four weeks. During these four weeks if you are randomly placed in the whole body vibration or exercise group will complete a core exercise training program. Performance, muscle soreness/pain, muscle activity, muscle damage, proprioception (being able to feel your body's position), posture, muscle oxygenation and physical exertion will be measured. The most likely risks from this study are falling, dizziness, nausea, or vomiting from whole body vibration, muscle soreness, pain or injury from road march, or pain, bruising, redness, swelling or infection from blood draws. As part of participating in this study you will receive monetary compensation and extra credit, if allowed by your professor. The alternative is to not participate.

You are invited to participate in a research study to determine how exposure to different types and intensities of whole body vibration (WBV) changes blood flow. WBV is a type of exercise machine that vibrates, stimulating muscles and nerves in the body. The study is being conducted by Dr. JoEllen Sefton, Director of the Warrior Research Center, and Kaitlin McGinnis, PhD student in the Auburn University School of Kinesiology.

Purpose: WBV has been shown to increase core stabilization muscle activation, decrease low back pain, increase proprioception, increase strength, and increase balance in both healthy participants and participants with chronic low back pain. Specifically in patients with chronic low back pain, WBV has been successful in decreasing low back pain likely because patients with low back pain regularly have deficits in core muscle activation and proprioception. We propose that WBV core muscle training may facilitation neuromuscular adaptations enabling participants to complete a road march with less resulting low back pain and improved performance.

What will be involved if you participate?

1. After you read this informed consent, a member of the research team will be available to answer any questions. If you decide to participate, you will sign the last page of the consent form. (Choosing to, or not to participate will not affect your relationship with Auburn University, Dr. Sefton, or the School of Kinesiology.)
2. In order to participate you must be a healthy adult between 19-35, with none of the following conditions:
    a. Acute inflammations and infections
    b. Acute joint disorders/arthroses
    c. Chronic migraine headaches
    d. Cardiovascular diseases, such as heart and vascular
    e. Recent joint implants such as foot, knee, and implants
    f. Heart rhythms/valve disorders
    g. Recently placed metal or synthetic implants such as pacemakers and cochlear implants
    h. Pregnancy, gallstones, epilepsy
    i. Recent thrombosis or possible thrombotic complaints
    j. Low back complaints such as acute hernia, discopathy, and spondylolysis
    k. Tumors, diabetes and kidney stones
    l. Have a current concussion or a concussion within the last 90 days
    m. Allergies to adhesives
3. You will be given a Warrior Research Center health questionnaire to complete. We will record your height, weight, gender, and age. You will be assigned a coded participant identification number allowing us to keep your data private.
4. You will be asked to schedule your first 8k road march
    a. During the road march you will walk at you own pace with a 35lb ruck sack for 8 kilometers.
5. Study Timeline
    a. First 8k Road March (~190 mins)
    b. 1 day follow-up from first road March (~30 mins)
    c. 2 day follow-up from first road march (~30 mins)
    d. Core Training (if you are randomly placed in the Whole body vibration or exercise group, (90 mins per week)
    e. Second 8k Road March (~190 mins)
    f. 1 day follow-up from second road March (~30 mins)

g. 2 day follow-up from second road march (~30 mins)
h. Total study time
    i. Whole body vibration group 770 mins
    ii. Exercise group 770 mins
    iii. Control group 500 mins

6. During the first and second 8 kilometer session we will measure:
    a. Low back pain/ muscle soreness
        i. You will be asked to complete a scale to determine your level of low back pain/soreness during the session
        ii. An algometer will be used to provide a more objective measure of muscle soreness. The algometer will be placed on your lower back and slowly pressed inwards. You will be asked to notify the research when you feel discomfort, which will end the test. This will be completed three times to provide the average score.
        iii. You will complete this scale and algometer measurement:
            1. Prior to road march
            2. Halfway through road march (no algometer measurement)
            3. Following road march
            4. 1 day following road march
            5. 2 days following road march
    b. Performance
        i. You will be asked to complete the road march in as little time as you can safely finish.
        ii. Time will be measure by a stopwatch
    c. Blood draws
        i. You will have approximately 6 millileters (one teaspoon) of blood drawn from a vein located in the area in front of your elbow. The needle and supplies used are sterile and similar to what is used by your physician's office to draw blood. It is important for you to follow all instructions provided in order to minimize any bruising and/or discomfort you may feel from the blood draw. In the extraordinarily rare event that medical care is needed following the blood draw, you will be instructed to proceed to the Auburn university medical clinic or EAMC. The certified tester will draw the blood using standard blood drawing techniques. The blood samples will be frozen and used in future analysis.
        ii. Blood draws will be taken:
            1. Prior to road march
            2. Following road march
            3. 1 day following road march
            4. 2 days following road march
    d. Muscle oxygenation
        i. You will be fitted with 3 EMG wireless sensors (about the size of a business card) with double sided tape, on the your stomach, lower back and hip. These will measure how hard your muscles are working.
    e. Proprioception
        i. You will be asked to sit in the Biodex Dynomometer chair. A strap will be placed around your upper torso and over your thighs. The Biodex seat will passively

bent you into a forward flexed posture. You will be asked to remember this position. The Biodex seat will then move you back upright. At this time you will be asked to return to the position that the Biodex had previously put you in. This process will be repeated 3 times and the average score will be taken.

ii. Proprioception measurements will be taken at:
   1. Prior to road march
   2. Following road march
   3. 1 day following road march
   4. 2 days following road march

f. Physical Exertion
   i. You will be asked to complete a scale to determine your level of exertion during the study (BORGS scale).
   ii. You will complete this scale:
      1. Prior to road march
      2. Halfway through road march
      3. Following road march
      4. 1 day following road march
      5. 2 days following road march

g. Heart rate and posture
   i. Heart rate and posture will be measured throughout your session with a Zephyr bioharness. The harness will be fit around your chest (just like wearing a heart rate monitor) by a researcher prior to the 8k road march and will measure both heart rate and posture throughout the road march.

7. Core Training (Whole Body Vibration and Exercise group only)
   a. You will be asked to come in three days a week for three weeks to complete core exercise training with or without whole body vibration
   b. Whole body vibration(WBV) is a low intensity exercise performed on an oscillating platform that produces vibrations. This has been shown to improve clinical and physical performance.
   c. Each session will last approximately 30 mins
   d. You will complete the following exercise 3 times for 30 seconds:
      i. Plank
      ii. Squat hold
      iii. Side plank
      iv. Bridge
      v. V-up hold
      vi. Back extensions
   e. Researchers will teach you how to perform these exercise at your first session and pictures will be set up to guide for future sessions

Potential risks and discomforts

1. We will show you the correct way to stand and will hold onto a bar to reduce the risk of falling or injury. Additionally a member of the research team will be present to correct positioning and prevent falls.
2. To prevent slight risk of dizziness, nausea, or vomiting you will be given breaks in between vibration sessions and will be monitored by a member of the research team. Additionally, if you experience any of these symptoms you can stop immediately.

3. While having your blood drawn there is a risk of pain, bruising where the blood is taken, redness, swelling and infection. There is also a slight risk of fainting when blood is drawn.
4. There is a risk of muscle soreness, pain or injury from completion of the road march. To reduce the risk of injury you will be asked to complete the road march at a pace you feel comfortable and a researcher will be present for all road marches. Additionally, a weight of 35lbs has been chosen for the road march, as it is the beginning weight for new Army recruits.
5. There is a risk of breach of confidentiality. To prevent this all documentation will be locked in filing cabinets in the office of the principal investigator to reduce the risk of breach of confidentiality.

In the unlikely event that you sustain an injury from participation in this study, the investigators will summon emergency help with a cell phone, but they have no current plans to provide funds for any medical expenses or other costs you may incur.

What are the possible benefits of participating in this research?

1. You may be able to receive extra credit for this study if allowed by your professor. You must check will your professor to determine if you are able to receive extra credit through SONA for this study. There are no other benefits to participating in this study.

Will I have to pay for anything if I take part in this research?

1. No, there will be no cost to you for your participation. Everything you need will be provided to you by the research team.

Will I be paid for my participation in this research?

1. Yes you will be paid 75 dollars if you complete the entire research study. You will receive 25 dollars for the first road march and the additional 50 dollars for the second road march You will not be paid if you only complete a portion of this study.

How will you protect my privacy and the confidentiality of records about me?

1. Each person who chooses to participate in this study will be given a participant number maintained on a master sheet. This sheet will be kept locked in the principal investigator's office (Dr. JoEllen Sefton) in a locked filing drawer.
2. All other data collected will be password locked, saved on a compact disc and will be anonymized. Only persons working on this project and listed on the Internal Review Board document will be able to view the information. Any information entered into the database will be maintained on a secure computer and backed up daily. All backups will be stored in the locked office of the Neuromechanics Laboratory coordinator.
3. Forms will be maintained in locked storage at all times. The database will be password protected and accessible only by the project researchers; the database will be on a single computer locked in a personal office that is only accessible to the Principal investigator and research investigators.

Authorized representatives of the following groups may need to review your research and/or medical records as part of their responsibilities to protect research participants:

1. Auburn University Institutional Review Board

What if I decide not to participate in this research?

1. Your participation in this research is voluntary. You may decline to participate now or stop taking part in this research at any time without any penalty or loss of benefits to which you are entitled. Deciding not to participate now or withdrawing at a later time does not harm or in any way affect current or future relationships Auburn University and the School of Kinesiology.
2. If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop

participating will not jeopardize your future relations with Auburn University, the School of Kinesiology, or the investigators.

What could end my involvement in the research?

1. The investigator or study sponsor may withdraw you from participating in this research. Non-compliance in undergoing vibration therapy, missing greater than two whole body vibration sessions, could result in you being eliminated from the study. The investigator will make the decision and let you know if it is not possible for you to continue. Your taking part in the study may be stopped without your consent if it is determined by the investigator that remaining in the study might be dangerous or harmful to you.
2. During the course of the research, the investigators will tell you of any new findings that might cause you to change your mind about continuing in the study. If new information is provided to you, the investigators will obtain your consent to continue participating in this study.

Your privacy will be protected. Any information obtained in connection with this study will remain confidential. Participant information, if published, will be submitted anonymously.

WHO SHOULD I CALL IF I HAVE QUESTIONS OR CONCERNS ABOUT THIS RESEARCH?

1. If you have questions about the research at any time, you should contact Dr. Sefton at (334) 844-1694 or jmsefton@auburn.edu or Kaitlin McGinnis at 484-364-9502 or by email at kdm0031@auburn.edu
2. If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334) 844-5966 or email at hsubjec@auburn.edu or IRBchair@auburn.edu

SIGNATURE OF RESEARCH PARTICIPANT

I have read the information provided above. I have been given an opportunity to ask questions and all of my questions have been answered to my satisfaction. Having read the information provided, you must decide whether or not you wish to participate in this research study. Your signature indicates your willingness to participate.

Printed Name of Participant

Signature of Participant Date

SIGNATURE OF PERSON OBTAINING CONSENT

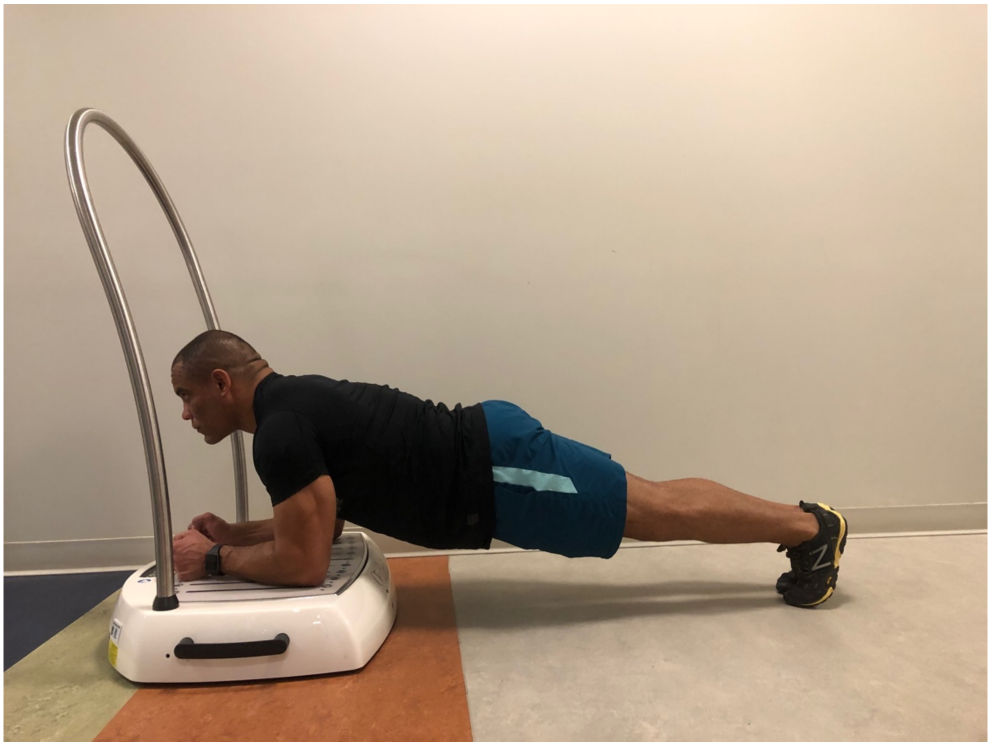
My signature certifies that the participant signed this consent form in my presence as his/her voluntary act and deed.

Printed Name of Person Obtaining Consent

Signature of Person Obtaining Consent

Appendix 3: Exercises

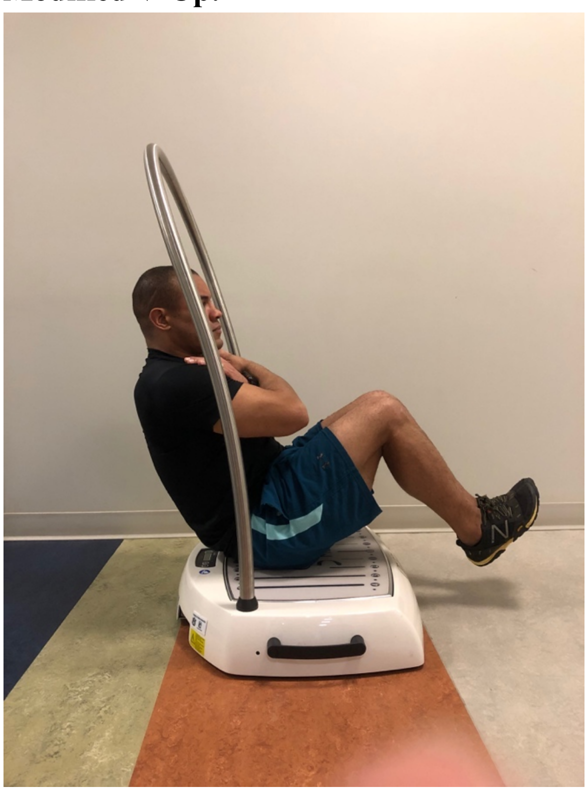
Plank:



Squat:

Side Plank:

Modified V-Up:



Bridge:

Back Extension:

Appendix 3: VAS

CIRCLE ONE: PRE 4k POST Foot March: 1 or 2

Visual Analog Scale

The Worst Imaginable Pain

No Pain

Appendix 5: BORG

BORGS Scale

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