# EFFECTS OF BACKPACK CHEST STRAPS ON SIMULATED SHOOTING PERFORMANCE FOLLOWING REPEATED BOUTS OF TREADMILL MARCHING

by

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# DEDICATION

In memory of my Nana, Toni Rittenberg. I'll never forget our many adventures, canasta nights, late night trips west or your patience on the phone while I attempted to describe my Montana experiences.

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# ABSTRACT

Effects of Backpack Chest Straps on Simulated Shooting Performance Following Repeated Bouts of Treadmill Marching

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Soldiers must quickly take action when called upon and normally carry heavy loads in the process. One piece of equipment that is vital to carrying this load is a backpack. While load carriage and physical performance have been researched in the past, it is unknown if changing the location of the shoulder and chest straps will influence physiological measures or marksmanship performance. PURPOSE: The purpose of this study was to examine how changing the location of backpack shoulder straps affect physiological and marksmanship values during a simulated road march while under army assault load conditions. METHODS: Seven young healthy men (Mean±SD: 22 ± 3.5 yrs; 24.75 ± 1.38 kg/m$^2$ BMI) participated in this study. Subjects wore load carriage equipment (body armor 8.05 kg, backpack 21.7 kg, rifle 3.25 kg) during three separate testing periods. Each period consisted of 120 minutes of marching and 6 minutes of shooting with an airsoft rifle equipped with a laser-based shooting system. Each of the lab visits corresponded to testing one of three chest strap conditions: modified chest strap (MCS), standard chest strap (SCS) and no chest strap (NCS). Heart rate, upper limb oxygen saturation, discomfort, shot accuracy and shot score were analyzed using repeated measures ANOVA ($\alpha$=.05). RESULTS**:** There were significant main effects of trial (p=0.018) and time (p=0.000) when examining discomfort. There was a significant main effect of trial (p=0.002) for upper limb oxygenation. There was also a significant trial (p=0.017) main effect for heart rate. There were no main effects for either shot score or shot accuracy. CONCLUSION**:** There were no significant differences in any marksmanship value. However, there were significant differences in heart rate, discomfort and upper limb oxygen saturation. This would suggest that the location of backpack shoulder straps may have an effect on physiological measures while having no effect on performance measures during a simulated road march.

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# CHAPTER ONE

# INTRODUCTION

## Background

Backpacks are a part of daily life for many people, ranging from school children and college students, recreational day hikers, to members of the military. In some communities, transporting goods with backpacks, or other load-carrying techniques, are a way of life. Two studies, for example, examined the unique load-carrying techniques in Nepalese porters (Bastien, Schepens, Willems, & Heglund, 2005) and in several African tribes (Maloiy, Heglund, Prager, Cavagna, & Taylor, 1986). The Nepalese porters utilized a head strap in place of shoulder straps to support their loads, which routinely weighed more than their own body weight (Bastien, Schepens, et al., 2005). In east Africa, the Luo and Kikuyu tribes each had a preferred way of carrying their respective loads of goods. The women of the Kikuyu tribe utilized a head strap to assist in carrying loads while the women in the Luo tribe balanced loads on top of their heads (Maloiy et al., 1986). Load carraige issues have also been evaluated for specific occupational settings, such as the use of satchels by mail carriers to carry their deliveries (Austin et al., 2005; Dempsey et al., 1996).

With extensive use of backpacks in everyday life and the workplace, companies continue to develop accessories that improve comfort without sacrificing functionality. The introduction of framed backpacks and backpack waist belts allowed recreational backpackers to carry heavier loads more easily and with greater comfort, but the backpack's shoulder straps still caused pain, numbness, and weakness in the upper extremities (Corkill, Lieberman, & Taylor, 1980; Nylund, Mattila, Salmi, Pihlajamäki, & Mäkelä, 2011; Rothner, Wilbourn, & Mercer, 1975). In fact, members of the United States military have reported the same symptoms during patrols with heavy backpacks (Corkill et al., 1980; Jones & Hooper, 2005; Knapik, Harman, & Reynolds, 1996; Knapik et al., 1997; Maurya, Singh, Bhandari, & Bhatti, 2009; Nylund et al., 2011; Rothner et al., 1975).

With the dangers of war, soldiers not only carry a backpack but also wear up to an additional 20.5 kg in body armor which dramatically increases their total load carriage (Crowder, Beekley, Sturdivant, Johnson, & Lumpkin, 2007; MilitaryMorons, 2009; Stevenson et al., 2004), and the energy cost of marching (Bastien, Schepens, et al., 2005; Bastien, Willems, Schepens, & Heglund, 2005; Beekley, Alt, Buckley, Duffey, & Crowder, 2007; Crowder et al., 2007; Maloiy et al., 1986; Sagiv, Ben-Gal, & Ben-Sira, 2000). Increased load carriage from heavy backpacks can also lead to greater fatigue as the percentage of upper body maximum strength used must increase in response to the heavier load (Knapik et al., 1996; Knapik et al., 1997; Nylund et al., 2011).

When suffering from pain, numbness, and/or weakness in the upper extremities from using backpacks with over-the-shoulder straps to carry a heavy load, the condition is known as backpack palsy, brachial plexus palsy, or simply pack palsy (Corkill et al., 1980). The underlying cause of backpack palsy is the mechanical compression of biological tissue by the shoulder straps when heavy backpack loads are carried. However, researchers have not yet agreed on the mechanism of this condition – i.e., does the mechanical compression of the shoulder straps cause a reduction of blood flow to the nerves, or does the compression cause a direct disruption of the nerves themselves? (Birrell & Hooper, 2007).

There are many factors to consider when examining how backpack straps apply pressure to the body. Factors examined by researchers include total backpack mass (Knapik et al., 1996; Knapik et al., 1997; Piscione & Gamet, 2006), backpack wearing location (Knapik et al., 1997; Macias, Murthy, Chambers, & Hargens, 2008), the differences between using one or two backpack shoulder straps (Legg & Cruz, 2004; Macias et al., 2008), and the use of chest straps (Hollins, Reinking, Pribanic, & Heil, 2013). Each of these studies examined how different load conditions and backpack variations effected physiological and/or performance measures.

There is one study that examined the use of different chest straps on both physiological (heart rate and energy expenditure) and functional performance (change in handgrip strength) during and following treadmill marching (Hollins, 2012). The function of a chest strap is to improve the ergonomics of load carriage by securing the backpack chest straps across the front of the torso. Hollins (2012) tested the effects of three different chest strap conditions: Using no chest strap, use of a standard chest strap, and use of a modified chest strap. Each chest strap condition caused the pressure from the backpack load to be focused on different parts of the shoulders which, it was theorized, could have caused differences in physiological and/or performance measures between conditions. For the no-chest-strap condition, the backpack's chest strap was simply not buckled which allowed the shoulder straps to migrate freely to the lateral part of the shoulders while treadmill marching. The standard chest strap condition, in contrast, used the backpack's own chest strap to pull the shoulder straps closer to the body's midline and stabilize their position while marching (which is the intended purpose of this chest strap). However, when used with body armor, the use of the standard chest strap causes the backpack's shoulder straps to ride just lateral of the armor's lateral shoulder border, which places pressure on that area of the shoulders. Finally, the modified chest strap condition used an after-market accessory that functions like the standard chest strap except that it attached to the armor which brought the backpack's shoulder straps much closer towards the midline of the body. Thus, use of this modified chest strap allowed the shoulder straps to ride on top of the armor while also limiting contact of the shoulder straps with the auxiliary region of the arm. In fact, the one company who manufactures and sells the modified chest strap have anecdotally suggested that use of their product should decrease symptoms related to backpack palsy. Lacking a means of measuring marksmanship at the time of the study, Hollins (2012) used change in handgrip strength as a performance measure, where handgrip strength was used as a surrogate indicator for changes in hand function. Though the use of handgrip strength was reasonable for this study, the measure of handgrip strength as a performance measure is not representative of an action a soldier may perform in the field (e.g., shooting performance). With the Hollins study missing an ecologically valid performance variable, as well as the inconclusive findings for the other variables, the true influence of these chest strap conditions on shooting performance after carrying a loaded backpack are still unknown.

## Statement of Problem

This study examined how the use of three chest strap conditions affect physiological and shooting performance measures while wearing upper body armor and carrying an army assault load during a simulated march.

## Research and Statistical Hypotheses

The null hypothesis was that neither physiological nor performance variables would differ significantly between the three chest strap testing conditions: 1. Use of no chest strap (NCS); 2. Use of the backpack's own "standard" chest strap (SCS); 3. Use of an after-market commercially-available "modified" chest strap (MCS) that pulls the shoulder straps off of the auxiliary arm. The alternative hypothesis was that dependent variables for the MCS condition would differ significantly from the SCS and NCS conditions – i.e., A decrease in self-reported measures of discomfort, higher measures of shooting performance, and higher oxygen saturation in the upper extremities.

$$H_0: \mu_{MCS} = \mu_{SCS} = \mu_{NCS}$$

$$H_A: \mu_{MCS} \neq \mu_{SCS} = \mu_{NCS}$$

Where: $\mu_{MCS}$, $\mu_{SCS}$, and $\mu_{NCS}$ are sample population means for each physiological and performance variable of interest in this study. The physiological variables include total hemoglobin and rating of perceived discomfort (RPD). The lone measure of performance will be derived from a stationary marksmanship test.

## Significance

This study may lead to a better understanding of how modified backpack equipment could lead to a reduction in self-reported discomfort and backpack palsy symptoms. Further, it is believed that shooting performance will not deteriorate when discomfort and backpack palsy symptoms are minimized. If this is true, then the use of the modified chest strap could allow soldiers in the field to shoot with greater accuracy when responding to threats.

## Delimitations

This study was delimited to ROTC members and subjects that were accustomed to carrying heavy loads. This study was also delimited to using a fixed load carried in the same backpack for each participant, to the use of submaximal treadmill walking, and to indoor shooting marksmanship with an airsoft rifled.

## Limitations

Since the armor vest and backpack must be fit to the test subject at the beginning of each test session, the fit of the backpack and armor vest will vary slightly from trial to trial. In addition, there is no way to quantify this degree of variation. Marksmanship proficiency will vary between subjects, as will the subjects' experience with shooting an airsoft rifle within an indoor laboratory setting. Moxy sensors measure 12mm deep and, depending on location, may not penetrate through fat tissue.

## Assumptions

It is assumed that subjects will follow all guidelines prior to each testing session. It is also assumed that subjects will understand all laboratory instructions and be truthful in their responses. Subjects' shooting ability and physiological responses to wearing upper body armor and backpack will not change over the course of the study (i.e., no adaptations).

## Definitions

| | |
|---|---|
| Airsoft rifle: | A rifle that uses a spring to create a realistic “popping” sound when fired. |
| Armored vest: | A military grade vest that is used to hold armor and serves as an attachment point of multiple accessories. |
| Backpack Palsy: | A condition that occurs in those carrying backpacks that can cause muscular weakness, numbness, tingling or cramping in the upper extremity. Also known as backpack palsy and brachial plexus palsy. |
| Backpack: | A device used to carry loads on the back that is secured to the body with over-the-shoulder straps and a waist belt. |
| Dominant hand: | The preferred hand to be used for pulling the trigger when firing a rifle. |
| Modified Chest Strap (MCS): | This is an after-market addition to a backpack that functions like a standard chest strap while also physically attaching the backpack shoulder straps to an armor vest worn underneath. This modified chest strap, called the Mystery Cinch™, is manufactured and sold by Mystery Ranch LTD (Bozeman, MT). |
| MOXY Monitor: | A near-infrared spectroscopy device that can be secured to the skin to collect and store THb measurements. |
| Near-Infrared Spectroscopy (NIRS): | Device that uses near-infrared light emitted into capillaries to determine oxygen saturation and total hemoglobin. |

| | |
|---|---|
| Standard Chest Strap: | A buckled strap that is used to attach and pull together the backpack shoulder straps on the front of the torso. |

Operational Definitions

| | |
|---|---|
| Discomfort rating: | The self-assessed rating of discomfort on a 0-10 scale, where discomfort was defined as distressing, irritating, or causing soreness. |
| Heart Rate: | Physiological measure of the rate (in beats per minute, or BPM) at which the heart is contracting. |
| Oxygen Atrial Saturation ($SaO_2$): | The percentage of hemoglobin (0-100%) that is bound to oxygen when compared to the total oxygen carrying capacity. Measured with catheters in arteries ($SaO_2$). |
| Oxygen Muscle Saturation ($SmO_2$): | The percentage of hemoglobin (0-100%) that is bound to oxygen when compared to the total oxygen carrying capacity. Measured in muscle capillaries using NIRS ($SmO_2$). |
| Oxygen Pulse Saturation ($SpO_2$): | The percentage of hemoglobin (0-100%) that is bound to Oxygen when compared to the total oxygen carrying capacity. Measured in muscle capillaries ($SpO_2$). Measured with a pulsometer, commonly on fingertip ($SpO_2$). |
| Kilopascal (kPa): | Standard unit of pressure where 1 kpa is equivalent to the pressure that a 10g mass puts on a 1cm2 area. |

Shooting Performance: The score from the total number of shots on a target where each ring is given point values of 5-10 with the center ring being 10 points and the outside ring being 5 points.

# CHAPTER TWO

# REVIEW OF LITERATURE

## Introduction

A successful mission, an operation assigned from commanding officer or higher-ranking official, is the standard measurement of progress for military operations. To achieve success, soldiers must prepare for and execute their orders for a mission. During the mission, the soldier must rely on their own abilities (Crowder et al., 2007) and their equipment (Bryant, Doan, Stevenson, Pelot, & Reid, 2001). For example, the total load carriage of the soldier has been shown to negatively influence physical performance as the carriage load increases (Hadid et al., 2017; Piscione & Gamet, 2006). When examining how backpack accessories, like an additional chest strap, influence load carriage, it is important to examine physiological and performance variables.

## Backpack Palsy

Brachial plexus palsy, or backpack palsy results from carrying heavy loads with a backpack that leads to an occlusion of blood, compression of nerves leading to the upper extremities or a cervical vertebrae traction injury (Birrell & Hooper, 2007; Bom, 1953; Corkill et al., 1980; Hadid et al., 2017; Knapik et al., 1996; Knapik, Reynolds, & Harman, 2004; Knapik, Reynolds, Orr, & Pope, 2016; Maurya et al., 2009; Nylund et al., 2011; Rothner et al., 1975). Symptoms of pack palsy can include experiencing cramping, muscle weakness, scapular winging, and paralysis in the upper extremities (Corkill et al., 1980; Knapik et al., 1996; Knapik et al., 2004; Knapik et al., 2016). Fortunately, these symptoms are usually temporary since most of those afflicted will experience a full recovery once they are no longer carrying a heavy load (Corkill et al., 1980; Knapik et al., 1996; Maurya et al., 2009; Nylund et al., 2011; Rothner et al., 1975). However, it has also been shown that continued exposure to the heavy load can cause backpack palsy symptoms to become chronic (Corkill et al., 1980; Knapik et al., 1996; Nylund et al., 2011).

While the pressure from heavy loads is known to cause backpack palsy, the specific mechanism is still unknown (Birrell & Hooper, 2007; Bryant et al., 2001; Hadid et al., 2017; Hollins et al., 2013). Researchers have suggested that blood flow occlusion, nerve compression, or a combination of both are the most likely mechanisms underlying the symptoms of backpack palsy. Backpacks have been shown to put upwards of 20 kPa pressure on the shoulders when it only takes 14 kPa to start causing blood flow occlusion (Bryant et al., 2001). Recently, Hadid et al. (2017) conducted a study and found that wearing a loaded backpack weighing 40% of the subjects' body mass resulted in a reduction in blood flow when measured at the finger. As a result, this reduced blood flow was shown to have negative effects on upper limb sensorimotor function, such as rifle marksmanship (Hadid et al., 2017).

## Physiological Measures

When researchers can conduct laboratory-based experiments, it is important to utilize the tools to which they have access. In most cases, these tools come in the form of physiological measuring devices. When looking for potential markers of backpack palsy, it may be beneficial to examine how measures of oxygen saturation, heart rate, or sensory function are changing between test conditions.

Oxygen Saturation

Oxygen saturation ($SO_2$) represents how much oxygen is bound to hemoglobin when compared to the total carrying capacity of hemoglobin (Mancini et al., 1994). Oxygen saturation is a measure of interest because it tells us how much oxygen is being supplied to the body during exercise. One study examined how oxygen supply can limit $VO_2$ in an isolated muscle (Richardson et al., 1999). To determine the oxygen saturation in the arteries, $SaO_2$ during each trial, Richardson et al. (1999) inserted catheters into the femoral and radial arteries. The samples taken from these catheters during exercise were analyzed to determine the $SaO_2$ during hypoxia, normoxia, and hyperoxia conditions. Richardson et al. (1999) found that $SaO_2$ was lower during hypoxia and higher during hyperoxia when compared to normoxia. The researchers also found that the higher $SaO_2$ measures caused muscular $VO_2$ to increase, suggesting that a change in $SpO_2$ will also cause a change in muscular performance. Another common method for measuring oxygen saturation is by finding pulse oxygenation, $SpO_{2,}$ with pulse oximeters. Hollins et al. (2013), for example, used a pulse oximeter on the index finger of the dominant hand of subjects during a loaded (47 kg) simulated march. These researchers found that fingertip oxygenation was significantly reduced after the march when compared to baseline measures.

Another measure that can be taken is muscle oxygen saturation ($SmO_2$). This value varies from $SpO_2$ because $SmO_2$ measures directly in the capillary beds of the targeted muscles, giving local oxygenation changes. A noninvasive technology for measuring $SmO_2$ in exercising muscles is near-infrared spectroscopy, or NIRS (Austin et al., 2005). A NIRS device uses the light absorption qualities of hemoglobin and myoglobin to determine their concentrations in the blood (Belardinelli, Barstow, Porszasz, & Wasserman, 1995). The NIRS device measures these concentrations by shining infrared light into the skin and measures the reflection at near infrared wavelengths in the arterial blood (Austin et al., 2005). Austin et al. (2005) determined the reliability of NIRS in collecting $SmO_2$ measures during exercise and found reliability scores of r = 0.87 and 0.88 for maximal treadmill running. These results show that a NIRS device is reliable for measuring $SmO_2$ during maximal running. Research using NIRS sensors for measuring $SmO_2$ have found that upper limb oxygenation significantly decreases while wearing a loaded backpack during standing stationary (Kim, Neuschwander, Macias, Bachman, & Hargens, 2014; Mao, Macias, & Hargens, 2015). Kim et al. (2014), for example, found that forearm oxygenation decreased by nearly 8% when their subjects wore 12 kg weighted backpacks for 10 mins, while Mao, Macias, & Hargens (2015) found that trapezius oxygenation was reduced by 22% after wearing a 10 kg backpack for only 10 minutes.

Heart Rate

Heart rate (HR) is one of the most commonly utilized physiological measures for monitoring exercise intensity within both research and health wellness settings. It well known that HR can increase due to an increased work rate of any level (American College of Sports Medicine 2010; American College of Sports Medicine 1998). This increased work rate can be caused by an increase in locomotion speed, an increased movement incline, as well as increased carriage load. It is well documented, for example, that HR will tend to increase with increase carriage load (Beekley et al., 2007). Beekly et al. (2007) tested subjects carrying loads equivalent to 30%, 50% and 70% of their body mass and found that each increase in weight resulted in higher heart rates than the lighter loads. In contrast, Knapik et al. (1997) wanted to examine the effects of different loads and found that the heart rate of subjects was higher when they carried a 34 kg backpack when compared to the other weights tested (48 kg & 61 kg). Thus, HR responses to carriage load are not always predicted by the magnitude of the load alone.

Knapik et al (1997) also found that utilizing a double backpack setup, using two backpacks to evenly balance weight on the back and front of the body, resulted in lower heart rates than using the standard single backpack setup. One study examining two different military load setups of 29.1 kg and 26.3 kg found that there we no differences in heart rate between the two load setups (Crowder et al., 2007). Another study examined if using various chests straps when carrying the same 33 kg backpack load during a simulated road march would influence heart rate, but there were no significant differences between chest strap conditions (Hollins, 2012). These findings would suggest that if the same load is carried within the same backpack between trials there should be no changes in heart rate between conditions.

Sensory Function

Another physiological measure that has been used to study backpack palsy is two-point discrimination (Hollins et al., 2013; Kim et al., 2014). This type of sensory test examines how far away from each other two points of pressure need to be in order for the subject to feel two distinct points (Nolan, 1982). Hollins et al. (2013) found that the use of a modified chest strap had no effect on two-point discrimination threshold on the back of the hand. In contrast, Kim et al. (2014) found a decrease in sensory function at the fingertip after subjects wore a 12 kg backpack for 10 minutes. These conflicting results may be due to the different locations used in each study.

In addition to two-point discrimination, some researchers have used Semmes-Weinstein monofilaments that use a single monofilament to apply pressure to the testing location. If the subject can not feel the monofilament, another monofilament with a larger diameter is used (Hadid et al., 2017; Kim et al., 2014). Hadid et al. (2017) found that the addition of a backpack loaded at 40% body mass while standing significantly increased the pressure threshold of the index and little fingers. Additionally, after 15 minutes of recovery the pressure threshold was still 20% greater than baseline measures in the index finger. Similarly, Kim et al. (2014) found significantly increased pressure thresholds in three of the four fingers tested after standing with a 12 kg backpack for 10 minutes.

## Marksmanship

Marksmanship is one of the key skills that soldiers must perform with high proficiency. The addition of a weighted backpack has been shown to decrease marksmanship performance (Hadid et al., 2017; Knapik et al., 1997; Tharion & Moore, 1993). Knapik et. al (1997) found that marksmanship performance decreased after a road march with loads of 34 kg, 48 kg, and 61 kg. These marksmanship decreases were temporary as they were only evident when subjects shot at the first target. Tharion & Moore (1993) found that soldiers marching on a treadmill with loads of 45 kg had a reduction in marksmanship as well. Specifically, the vertical stability of the rifle was the main contributor to the decrease in marksmanship (Tharion & Moore, 1993). These results would suggest that muscular fatigue of the upper extremities is the cause of decreased marksmanship. Both of these studies hypothesized that the reduction in marksmanship was a result of upper body muscular fatigue due to the added energy expenditure required to stabilize the upper body while carrying a heavy load (Knapik et al., 1997; Tharion & Moore, 1993). These results suggest that it would be expected for marksmanship to decrease after a prolonged load carriage march.

Hadid et al. (2017) found that shot location had a 34% increase in distance from the center of a target when comparing baseline measures and measures recorded after subjects wore a backpack (40% of body weight) for 45 minutes and allowed to recover for 15 minutes. Unlike previous studies, this decrease in performance was not attributed to muscular fatigue since there was no marching accompanying the added load carriage. The lack of a physical task would suggest that the lone factor that lead to a decrease in marksmanship was the addition of a weighted backpack (Hadid et al., 2017).

## Backpack Pressure and Discomfort

When designing a backpack, factors of functionality and comfort must be considered. In particular, the shoulders are a main concern as it has been shown that the shoulders have the highest amount of self-reported discomfort during a loaded road march (Birrell & Hooper, 2007; Bryant et al., 2001). For example, Birrell & Hooper (2007) found that the shoulders had the highest rate of discomfort among all upper extremity locations during a road march with a 20 kg backpack. When the researchers compared the discomfort ratings of subjects that finished the march with those that did not finish it was found that those that did not finish the march reported higher shoulder discomfort during the beginning of the march (Birrell & Hooper, 2007). Other discomfort locations that were reported were the neck, upper back, as well as the hands and arms (Birrell & Hooper, 2007). Shoulder discomfort was also reported by subjects in the Bryant et al. (2001) load carriage study. Another finding of the Bryant et al. (2001) study is that 95% of soldiers reported discomfort in the shoulders when the pressure was above 20 kPa and 90% reported discomfort when shoulder pressure was over 18 kPa. Both of these values are over the pressure required to cause blood flow occlusion, 14 kPa (Bryant et al., 2001).

## Summary

Equipment plays a key role in how effective a soldier can operate in the field. As some of the previous studies found, the health of a soldier can be negatively impacted by heavy load carriage. This negative health impact can then cause decreases in physiological and performance measures. If a soldier can operate without any decrease in physiological or performance measures, then the chances of them completing a mission successfully increases.

# CHAPTER THREE

## EFFECTS OF BACKPACK CHEST STRAPS ON SIMULATED SHOOTING PERFORMANCE FOLLOWING REPEATED BOUTS OF TREADMILL MARCHING

Contribution of Authors and Co-Authors

Manuscript in Chapter 3 Author: Dustin T. Kidd

Contributions: Primary investigator and developer of study methodology, directed data collection, processed and analyzed data, developed conclusions, and authored the manuscript.

Co-Authors: John G. Seifert

Contributions: Dr. Seifert assisted with development of study methodology, reviewed manuscript, aided in the development of conclusions.

Co-Authors: Mary Miles

Contributions: Dr. Miles assisted in data analysis and processing, reviewed and recommended changes to manuscript.

Co-Authors: Rob M. Orr

Contributions: Dr. Orr reviewed and recommended changes to the manuscript.

Manuscript Information

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## Introduction

In the military, soldiers routinely travel by foot while carrying their gear in backpacks. The topic of load carriage has been popular for researchers because added loads during locomotion tends to influence measures of physiological and physical performance (Bastien, Schepens, et al., 2005; Bastien, Willems, et al., 2005; Beekley et al., 2007; Hollins, 2012; Knapik et al., 1997). Knapik et al. (1997), for example, found that time to complete a 20 km self-paced road march increased as loads carried increased (34 kg, 48 kg and 61 kg). Further, in the same study Knapik et al. (1997) also found that marksmanship decreased for each weight after the soldiers completed weighted marching trial. With soldier carriage loads continuing to increase in recent years (Knapik et al., 2004), the physiological demands on the body continue to increase such that muscular fatigue begins to have a greater influence on soldier performance (Piscione & Gamet, 2006; Tharion & Moore, 1993). Piscone & Gamet (2006) found, for example, that wearing a loaded backpack significantly decreased time to exhaustion of the upper extremities when compared to an unloaded condition. Further, Tharion & Moore (1993) hypothesized that fatigue of the upper extremities may make it more difficult to perform gross and fine motor functions, such as firing a weapon.

The use of high carriage loads for long time periods has also given rise to the clinical condition called brachial plexus lesion, or backpack palsy (Birrell & Hooper, 2007; Bom, 1953; Corkill et al., 1980; Hadid et al., 2017; Knapik et al., 1996; Knapik et al., 2004; Knapik et al., 2016; Maurya et al., 2009; Nylund et al., 2011; Rothner et al., 1975). This condition is characterized by upper extremities experiencing cramping, muscle weakness, scapular winging, and paralysis (Corkill et al., 1980; Knapik et al., 1996; Knapik et al., 2004; Knapik et al., 2016). While there are likely several contributing factors underlying the cause of backpack palsy, the primary cause is believed to be compression of the shoulder's brachial plexus nerves, or occlusion of blood flow, by the shoulder straps of heavily loaded backpacks (Birrell & Hooper, 2007; Bom, 1953; Corkill et al., 1980; Hadid et al., 2017; Knapik et al., 1996; Knapik et al., 2004; Knapik et al., 2016; Maurya et al., 2009; Nylund et al., 2011; Rothner et al., 1975). Hadid et al. (2017) observed a decrease in microvascular blood flow in the finger after only 15 minutes of standing while wearing a loaded backpack at 40% of body mass. Additionally, Hadid et al. (2017) also found that subjective measures of discomfort continuously increased throughout their standing period of 45 minutes. In a majority of backpack palsy cases, recovery may take up to three months, but adverse symptoms can start to dissipate immediately after the load is removed (Corkill et al., 1980; Knapik et al., 1996; Maurya et al., 2009; Nylund et al., 2011; Rothner et al., 1975). In some cases, however, where there was continuous exposure to the heavy load, the symptoms became chronic (Corkill et al., 1980; Knapik et al., 1996; Nylund et al., 2011)

One of the suspected causes of backpack palsy is an occlusion of blood to the upper extremity (Hadid et al., 2017; Kim et al., 2014; Piscione & Gamet, 2006). Several studies have used various methods, such as photoplethysmography and near-infrared spectroscopy, to examine the blood flow and oxygen saturation to the arm during loaded and unloaded conditions (Hadid et al., 2017; Kim et al., 2014). Hadid (2017) conducted two studies and found that the microvascular blood flow in the index finger had decreased by 40% after 15 minutes of stationary standing with a load that was 40% of body mass. Similarly, Kim et al. (2014) found that students wearing a 12 kg backpack resulted in 50% reduction of microvascular blood flow in the forearm after only 10 minutes of standing. The results from these studies show that simply wearing a loaded backpack can decrease the blood flow to the upper extremities.

Some studies have used measures of shooting marksmanship (i.e., distance from the center of the target) as indicators of performance when examining how load carriage impacts soldiers (Hadid et al., 2017; Knapik et al., 1997). Hadid (2017), for example, found that marksmanship performance decreased after 45 minutes of stationary standing with a loaded backpack weighing 40% of body mass. Similarly, Knapik et al (1997) found that marksmanship decreased by 33% after a fast march with a heavy (34 kg) load.

With load carriage playing a significant role in how soldiers perform, it is important for backpack companies to design their products in a way that minimizes the effects of heavy load carriage on physical performance. Companies have certainly made their products stronger and lighter over the years, but military loads continue to increase as new tactical equipment is created. One backpack product with positive antidotal reports from soldiers is a modified chest strap (Mystery Cinch™; Mystery Ranch, Bozeman, MT) that forces the backpack shoulder straps to ride on top of the armor vest instead of migrating laterally to the shoulders. This chest strap connects directly into the chest of the armor vest and then wraps around the shoulder straps of the backpack to pull the shoulder straps towards the midline of the body. The new shoulder strap position created by the modified chest strap is then held in position on the armor with quick-release snaps. By design, the pressure from the backpack is applied to the shoulder area of the armor vest, which, according to the company, will reduce compression on the brachial artery and brachial plexus. Only one study has previously examined the potential influence of chest straps, including this modified chest strap, on select physiological and performance measures. Hollins et al (2013) compared the influence of three chest strap conditions, but the results were inconclusive, and they did not include measures of marksmanship or backpack palsy symptoms (Hollins et al., 2013).

The purpose of this study was to determine if marksmanship or physiological measures are affected by using different chest strap configurations. The current study was designed to build upon those of Hollins et al. (2013) by comparing the same chest strap conditions but using a different testing protocol, better measures of blood oxygenation, as well as measures of marksmanship and self-report measures of discomfort. Specifically, the potential influence of three chest strap conditions (i.e., the same as those previously investigated by Hollins (2012)) on measures of heart rate, upper limb blood oxygen saturation, marksmanship, and self-report measures of discomfort, were examined during a 126-minute simulated march with a 21.7 kg backpack load. It was hypothesized that the use of a modified chest strap would result in different marksmanship and physiological values when compared to using a standard chest strap or no chest strap.

## Methods

### Subjects

Thirteen male subjects between 18 and 45 years of age, all of whom were experienced heavy backpack load carriers and rifle shooters were recruited from the Gallatin County, Montana, area (e.g., ROTC, active duty military, reserves, and hunters). The subjects completed an informed consent document, as well as a health history questionnaire, both of which were approved by the Montana State University Institutional Review Board.

Experimental Design

A within-subjects, counterbalanced study design was used to compare three chest strap conditions tested (i.e., the independent variable): No chest strap (NCS), the standard chest strap (SCS), and the modified chest strap (MCS). The dependent variables included steady-state heart rate (HR, BPM), rating of perceived discomfort (RPD), oxygen saturation ($SmO_2$, %), and marksmanship. Each subject participated in a total of four lab visits: An orientation visit and three subsequent testing visits. The three subsequent visits were separated by one week and included testing where the subject was randomly assigned to one of three conditions: NCS, SCS, or MCS.

The NCS condition places no restrictions on the shoulder straps, which allowed the backpack shoulder straps to migrate both medially and laterally while marching, though the common tendency was for these straps to migrate laterally toward the anterior deltoid. The SCS condition represents using the standard chest strap that comes attached to the backpack at the time of purchase. Unlike the NCS condition, the backpack's chest strap is used to attach the shoulder straps on the front of the chest so that the shoulder straps are drawn towards the midline of the body. When used with body armor, use of the SCS often causes the anterior portion of the shoulder straps to ride just lateral of the armor vest. Finally, the MCS condition uses an after-market accessory that functions like the standard chest strap except that it attaches to the armor vest and brings the shoulder straps towards the midline of the body. Use of this product is described by the manufacturer as allowing the shoulder straps to ride on the armor and allow limited contact between the shoulder straps and the auxiliary regions of the arms.

## Procedures

During the first visit, subjects completed paperwork, had demographic data recorded, and were habituated to the marksmanship testing equipment and protocol. The habituation process consisted of the subjects being sized for the backpack, putting on the backpack and shooting the rifle with the backpack on until they felt confident in their shooting ability. Once the subject felt accustomed shooting the rifle, they were guided through a shot test. The shot test consisted of taking 10 shots at the designated target. After the first test was completed the subject was allowed to take a short rest before completing the test for a second time. The chest strap conditions mimicked the conditions used in the Hollins (2012) study.

For each of lab visit, subjects were asked to wear athletic clothing and their own choice of footwear with the footwear kept consistent between all testing visits. The subjects were also asked to avoid exercise for 36 hours before their designated testing visit. This avoidance of exercise was done to ensure that no physiological or performance changes could be attributed to prior muscular fatigue. The subjects oversaw their own meals before testing but were asked to eat the same type of meal before each visit for consistency. Each testing visit lasted 150 minutes and consisted of 24 minutes of preparation and a 126-minute testing period.

After completing paperwork during the first lab visit, subjects familiarized themselves with the rifle with target practice in the lab. Once familiar with the rifle, the subject performed a 10-shot marksmanship test from a standing position. Subjects were instructed to stand behind a designated mark on the treadmill while firing, as well as to fire as soon as they were back on target following each shot. Subjects were firing at a 9 cm sized target that was 9.3 meters away from where the subjects were standing, the same setup used for testing. The results of this shooting test were then arranged into total score and hit percentage to be used as baseline measures for each subject.

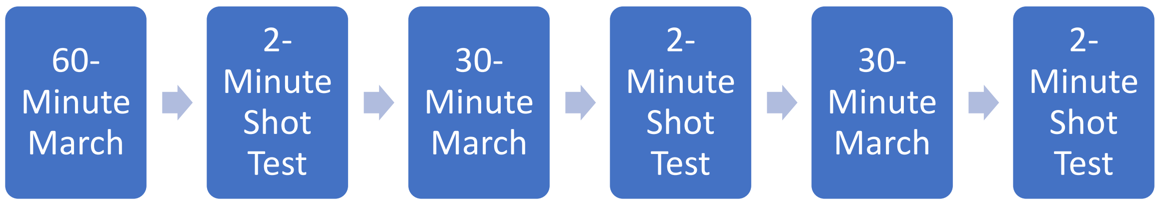
The next three testing visits consisted of three rounds, one 60-minute round and two 30-minute rounds of marching and two minutes of marksmanship testing which totaled 120 minutes of marching and 6 minutes of marksmanship testing. Prior to each march, the subject was fit with physiological measurement equipment (heart rate and muscle oxygenation monitors), an armored vest (8.05 kg), a loaded backpack (21.7 kg), and an airsoft rifle (3.25 kg). Next, the participant began marching the 60-minute bout on the treadmill at 4.8 KPH (3.0 MPH) and 2.0% grade with instructions to actively hold the airsoft rifle with both hands (i.e., Without the use of a shoulder sling or passively supported by the armor vest). During each march, the subjects were verbally reminded to not self-adjust the backpack shoulder straps to alleviate discomfort. It was believed that allowing self-adjustment during these trials would confound the meaning of all physiological, self-report, and performance measures during that trial.

During each marching bout, both heart rate (bpm) and $SmO_2$ (%) were continuously recorded while self-reported ratings of perceived discomfort (RPD) were assessed during the last two minutes. Measures of RPD used a 0-10 scale with 0 being "no discomfort" and a 10 being "severe discomfort" (Hernandez, Alhemood, Genaidy, & Karwowski, 2002) at 26 specific locations: right side of neck, right shoulder, right upper arm, right lower arm, right hand, right fingers, right lower back, right thigh, right calf, left side of neck, left shoulder, left upper arm, left lower arm, left hand, left fingers, left lower back, left thigh, left calf. The arm locations were chosen so any downstream discomfort caused by the backpack could be isolated to a specific area. The lower back was also chosen due to reports of soldiers commonly reporting lower back discomfort during prolonged marches. However, it was hypothesized that the back and leg locations would serve as a control location as it was hypothesized that discomfort in these locations would not be impacted by using a chest strap. The locations for RPD assessment, as well as the 0-10 RPD assessment scale itself, were viewable on a poster mounted in front of the treadmill so that subjects could quickly and easily assess RPD for each location. The list of RPD assessment locations were based upon pilot work in our lab, as well as a need for control locations. All of the locations around the shoulders, arms, and hands, for example, were all locations where discomfort was expected, whereas the lower back and leg locations were not expected to change across testing conditions.

At the end of the 60-minute marching bout, the treadmill was stopped, and the participant was instructed to turn counterclockwise about 120°, walk to a mark at the end of the treadmill, and then begin a standardized test of shooting marksmanship. This test began with a verbal command to take aim, at which point the participant raised the rifle and held a steady aim on the target (9cm, 9.3 meters away on the other side of the lab with no visual obstructions). After five seconds of aiming, the subject was verbally given a command to “fire!”, after which the subject was instructed to maintain aim on the target until, after another 15 seconds, they were verbally instructed to “Fire!” again. This sequence of aiming and firing was then completed a third time, after which the subject was instructed to “rest”, which meant to lower the rifle from the aiming position and wait for another command. After 30 seconds of rest, the subject went through the exact same shooting sequence as just described. After the third shot of the second shot sequence, the subject walked back to the front of the treadmill and started their next 30 minutes of marching. This marching and shooting series just described was then repeated for two 30-

minute marches successively for a total of 120 minutes of marching, 126 minutes total testing time, and 18 total shots taken. Below is a visual chart of the testing protocol described above.

Figure 3.1 Testing Protocol




<u>Instrumentation</u>

Body height and mass were measured using a mechanical beam scale with height rod (Health O Meter Professional, McCook, IL, USA). Heart rate (HR) was monitored and recorded with telemetry-based HR monitors (Polar Accurex Plus; Polar Electro, Inc., Lake Success, NY, USA). Subjects wore the Modular Tactical Vest (Marine Family of Improved Load Bearing Equipment) that they were fitted for and there was a Mystery Cinch (Mystery Ranch, Bozeman, MT, USA) attached to the chest webbing, even when it was not being tested. Loads for this study were determined through pilot testing and carried using a backpack (Marine Family of Improved Load Bearing Equipment). The $SmO_2$ monitors (Fortiori Design LLC, Hutchinson, Minnesota, USA) were placed on the brachialis and flexor carpi radialis of each arm, as well as the lateral head of the right gastrocnemius. The arm placement of the $SmO_2$ monitors was based upon our lab's pilot work prior to the study, while the gastrocnemius location was designed to serve as a control location (i.e., no changes in $SmO_2$ expected across testing conditions).

All testing, marching, and shooting, was completed on an oversized treadmill that is 2.44 meters wide and 3.05 meters long (Fitnex Fitness Equipment, Inc., Irving, TX, USA). Marksmanship values were collected using an airsoft M4 rifle (J.G. Works, Hong Kong) equipped with a red dot scope (Element Airsoft, GuangZhou, China) sitting on a riser mount (Leapers, Inc., Livonia, MI, USA). Subjects fired at a target stand (Triumph Systems, St. Louis, MO, USA) that held a reflective Sport II Laser Firing System target (Noptel, Oulu, Finland). The Sport II Laser Firing System (Noptel, Oulu, Finland) and accompanying software were used to measure and store marksmanship results.

## Data Processing

While HR and $SmO_2$ were continuously recorded during all testing, data from the last two minutes of each marching bout were averaged for subsequent analyses. Software from the Sport II Laser Firing System (Noptel, Oulu, Finland) was used to calculate and store marksmanship measures, which included hit percentage (defined as hits/total shots) and the total score (defined as the sum of all shot scores for an individual trial). These marksmanship measures were then averaged for each subject within each 3-shot shooting trial for subsequent analyses.

## Pilot Work

Prior to conducting the study, pilot testing was completed to investigate the load carriage and marksmanship parameters of the present study. Using a one-hour march and lighter backpack load to that described for the present study, the subjects reported minimal values of discomfort for all chest strap conditions and demonstrated no significant changes in marksmanship. We suspect that these results were caused, in part, by a relatively light backpack load (i.e., the load was not great enough elicit backpack palsy symptoms).

## Statistical Analysis

Two analysis were performed. The first analysis was done analyzing all subjects that were able to complete all trials. The second analysis was done using all subjects that completed at least 60-minutes of every trial. Measures of HR, $SmO_2$, marksmanship, and RPD were evaluated using multivariate two-factor (Test Condition (3) x Marching Bout (3)) repeated measures ANOVA ($\alpha = 0.05$) for the analysis of those that completed all three trials. For the 60-minute analysis, a one-way ANOVA was used ($\alpha = 0.05$). In addition, a Bonferroni post-hoc test was used to evaluate all pairwise comparisons ($\alpha = 0.05$). Finally, all ANOVA and post-hoc analysis was performed using SPSS (version 25.0, IBM Corp., Armonk, NY) while calculated effect sizes were performed using Microsoft Excel (version 16.19, Microsoft Corp., Redmond, Washington).

Cohens d was calculated for any non-significant post hoc results. This is a common effect size calculation that uses means and a pooled standard deviation. The results can be explained as small (0.2), medium (0.5), or large (0.8) (Watson, 2016). The equation used is as follows:

Equation 1. Cohens d Effect Size

$$Effect\ Size = \frac{Mean\ of\ experimental\ group - Mean\ of\ Control\ Group}{\sqrt{(SD\ of\ experimental\ group^2 + SD\ of\ Control\ Group^2)/2}}$$

# Results

Out of the thirteen subjects tested only seven were able to complete every trial. This caused the initial analysis to have a sample size reduction from 13 to 7.

Shoulder and Upper Limb Discomfort No significant time by trial interactions were observed for shoulder and upper limb discomfort (p=0.820). The effect size of the interaction was 0.01, suggesting a small effect. However, significant main effects of the trial (p=0.018) and time (p=0.000) were observed. Subjects did not report any difference in discomfort between the MCS (3.506 ± 1.91) condition and either the SCS (3.649 ± 1.91) or NCS (4.179 ± 2.40) conditions. The effect size between the MCS and NCS conditions was 0.31, suggesting a small effect. The effect size between the MCS and SCS conditions was 0.07, suggesting no effect. Subjects reported greater discomfort in the NCS condition (4.179 ± 2.40) than in the SCS condition (3.649 ± 1.91). Subjects also reported greater discomfort at 90-minutes (3.833 ± 1.97) than at 60-minutes (3.196 ± 1.66) and reported greater discomfort at 124-minutes (4.304 ± 2.22) than at 90-minutes (3.833 ± 1.97). The discomfort values at 60-minutes (3.196 ± 1.66) were also lower than those at 124-minutes (4.304 ± 2.22).

Figure 3.2: Trial Effects on Upper Limb Discomfort
*Indicates a significant difference compared to the NCS condition ($p < 0.05$)

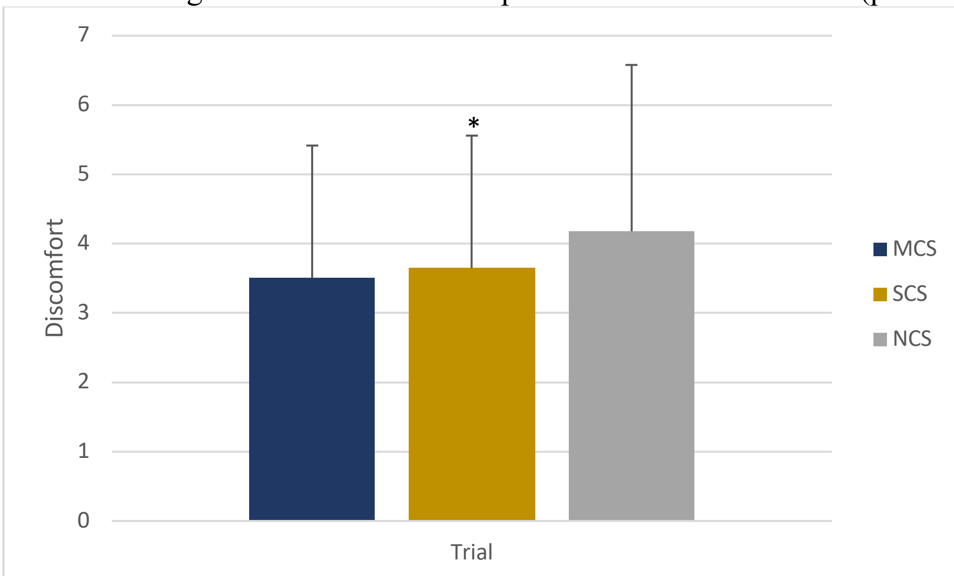
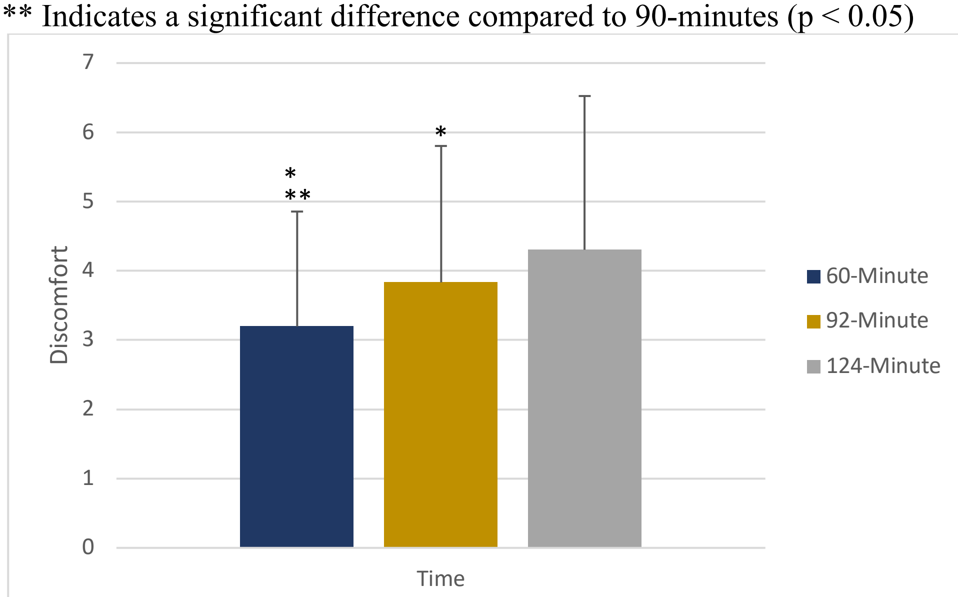



Figure 3.3: Time Effects on Upper Limb Discomfort
*Indicates a significant difference compared to 124-minutes ($p < 0.05$)
** Indicates a significant difference compared to 90-minutes ($p < 0.05$)




Upper Limb $SmO_2$ A significant main effect of trial (p=0.002) was observed for upper limb $SmO_2$. However, no main effect of time (p=0.333) was observed for upper limb $SmO_2$. The effect size for time was 0.12, suggesting no effect. Higher $SmO_2$ values were recorded during the MCS condition (65.84 ± 17.52) than in either the SCS condition (57.87 ± 18.44) or the NCS condition (56.01 ± 17.89). The effect size between the SCS and NCS conditions was 0.10, suggesting no effect.

Figure 3.4: Trial Effects on Upper Limb $SmO_2$
*Indicates a significant difference compared to the NCS condition ($p < 0.05$)
**Indicates a significant difference compared to the SCS condition ($p < 0.05$)

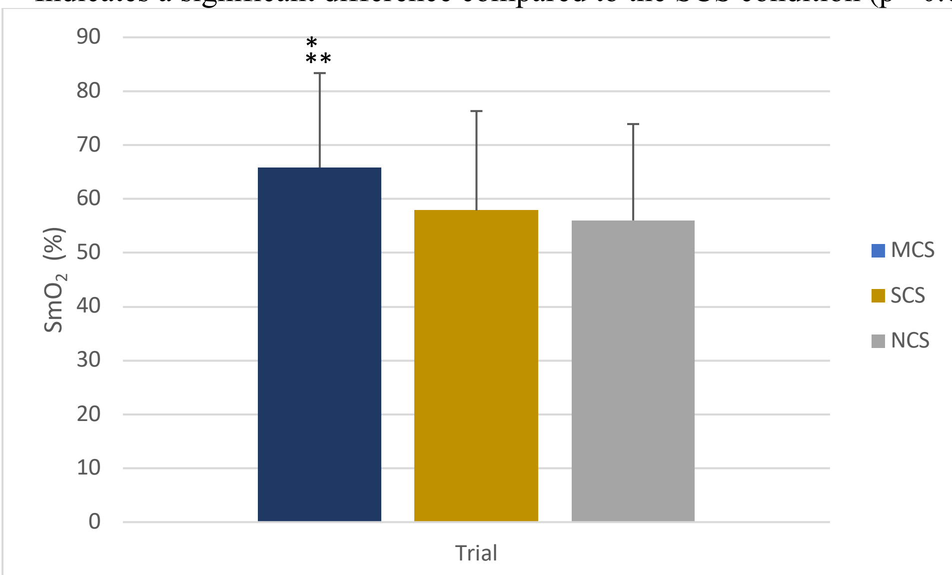
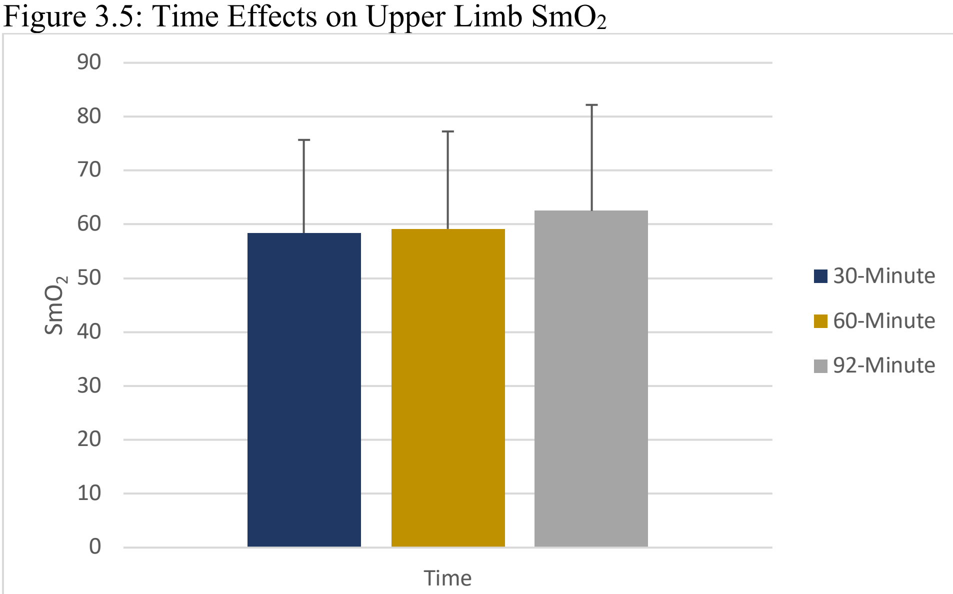



Figure 3.5: Time Effects on Upper Limb $SmO_2$



Heart Rate There was a significant trial main effect (p=0.017) for heart rate. However, there was no time main effect (=0.585) for heart rate. The effect size for time was 0.14, suggesting little to no effect. Heart rate was significantly higher in the NCS (134 ± 20 BPM) condition when compared to both the MCS (123 ± 19 BPM) and SCS (123 ± 19 BPM). The effect size between MCS and SCS conditions was 0.02, suggesting no effect.

Figure 3.6: Trial Effects on Heart Rate
*Indicates a significant difference compared to the NCS condition ($p < 0.05$)

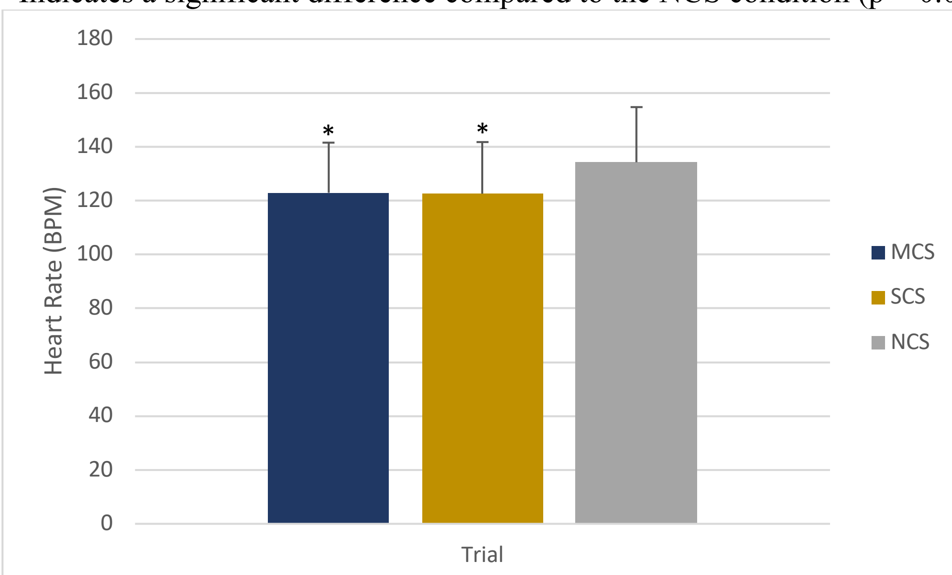
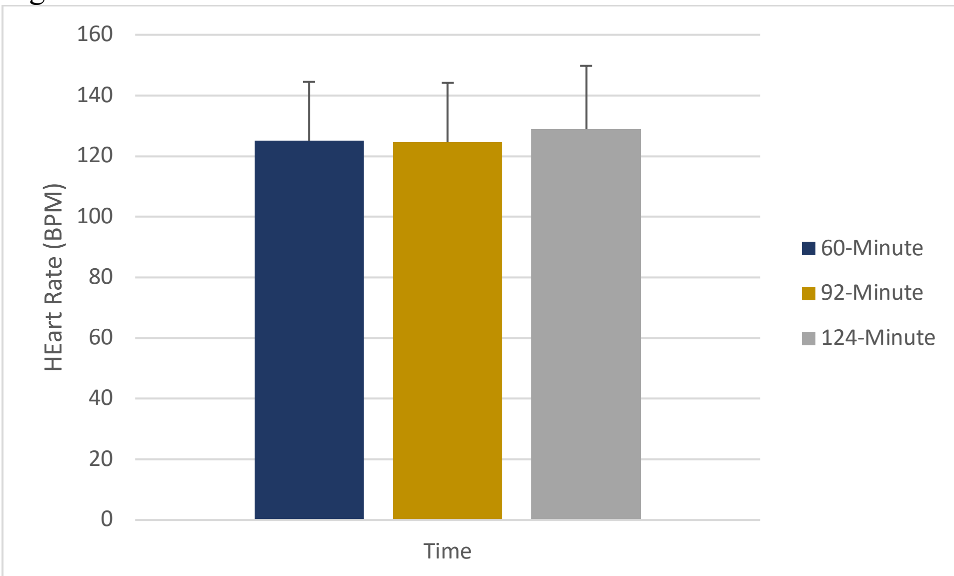


Figure 3.7: Time Effects on Heart Rate




<u>Shot Score</u> No significant time by trial interaction was observed for a shot score (p=0.822). There was also no significant trial (p=0.673) or time (p=0.506) main effects for the shot score. The effect size for trial was 0.17, suggesting a small effect. The effect size for time was 0.16, suggesting a small effect.

Figure 3.8: Trial Effects on Shot Score

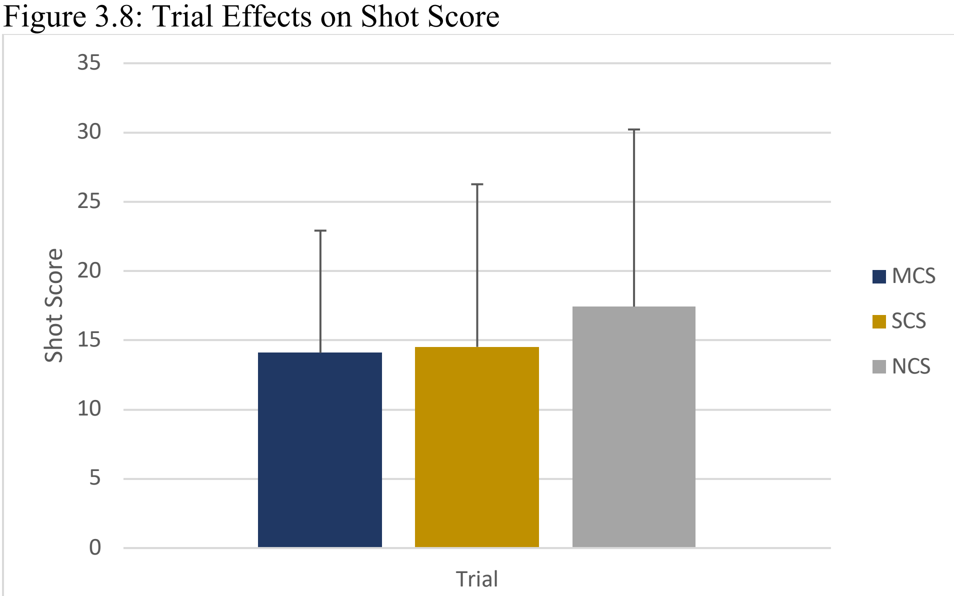
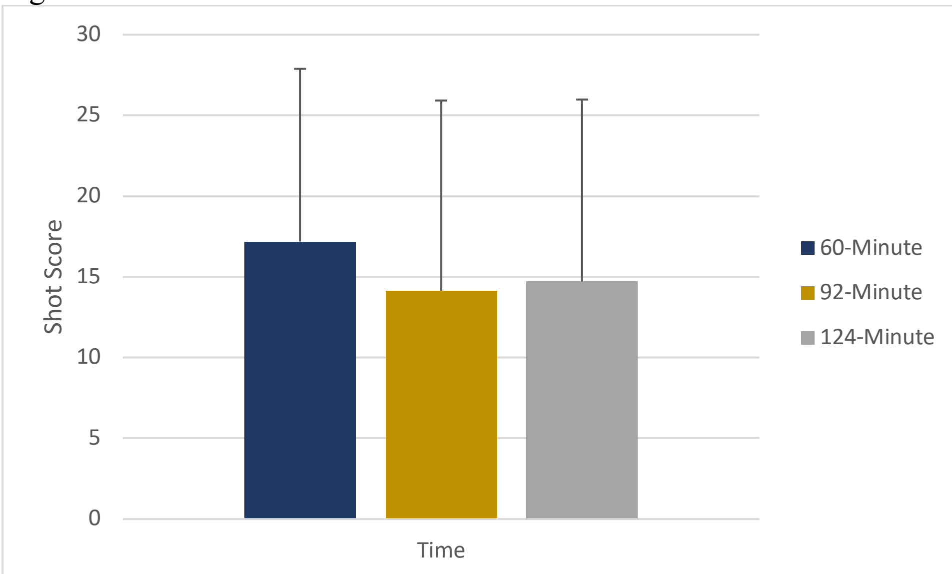


Figure 3.9: Time Effects on Shot Score




Accuracy No significant time by trial interaction was observed for accuracy (p=0.950). There was also no significant trial (p=.0293) or time (p=0.713) main effects for accuracy. The effect size for trial was 0.16, suggesting a small interaction. The effect size for time was 0.08, suggesting no interaction.

Figure 3.10: Trial Effects on Shot Accuracy

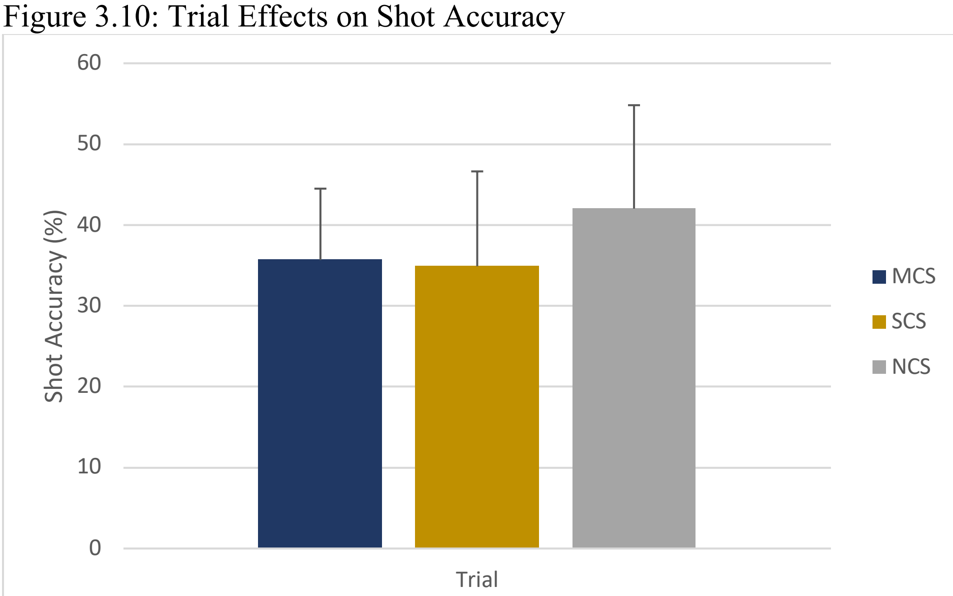
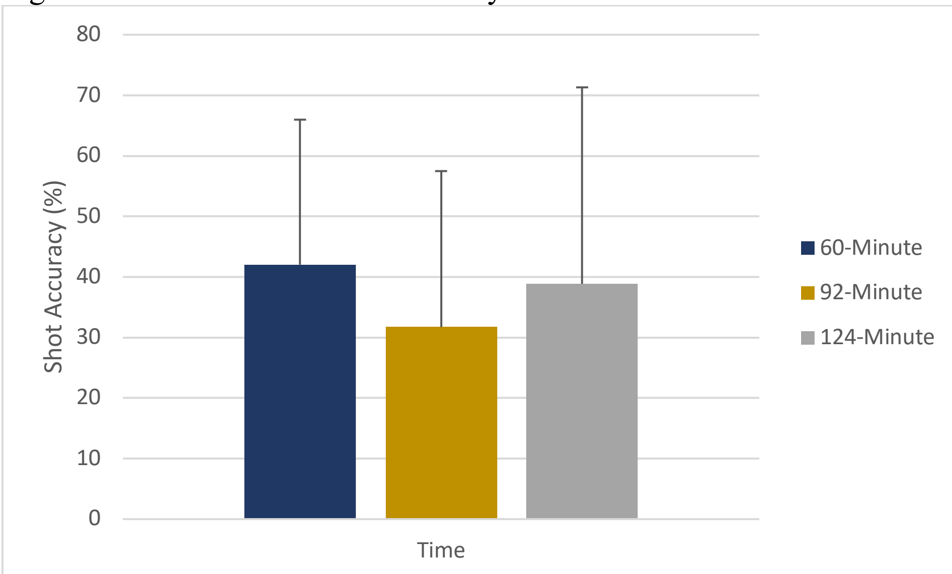


Figure 3.11: Time Effects on Accuracy




Total Body Discomfort No significant time by trial interaction was observed for total body discomfort (p=0.141). There was significant time (p=0.000) and trial (p=0.000) main effects observed. Subjects reported higher discomfort in the NCS condition (3.356 ± 2.25) than in the MCS condition (2.766 ± 1.79) and higher discomfort in the SCS condition (3.188 ± 1.09) than in the MCS condition (2.766 ± 1.79). The effect size between the SCS and NCS conditions was 0.10, suggesting no effect. Subjects also reported more discomfort at 92-minutes (3.148 ± 1.97) than at 60-minutes (2.575 ± 1.66) and reported more discomfort at 124-minutes (3.586 ± 2.22) than at 90-minutes (3.148 ± 1.97). The discomfort at 60-minutes (2.575 ± 1.66) were also lower than those at 124-minutes (3.586 ± 2.22).

Figure 3.12: Trial Effects on Total Body Discomfort
*Indicates a significant difference compared to the NCS condition ($p < 0.05$)
**Indicates a significant difference compared to the SCS condition ($p< 0.05$)

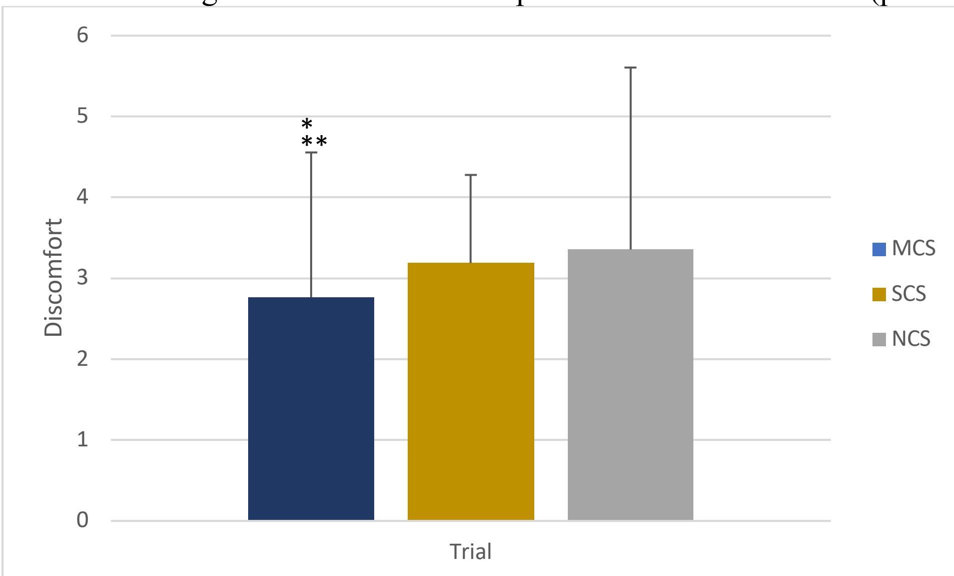
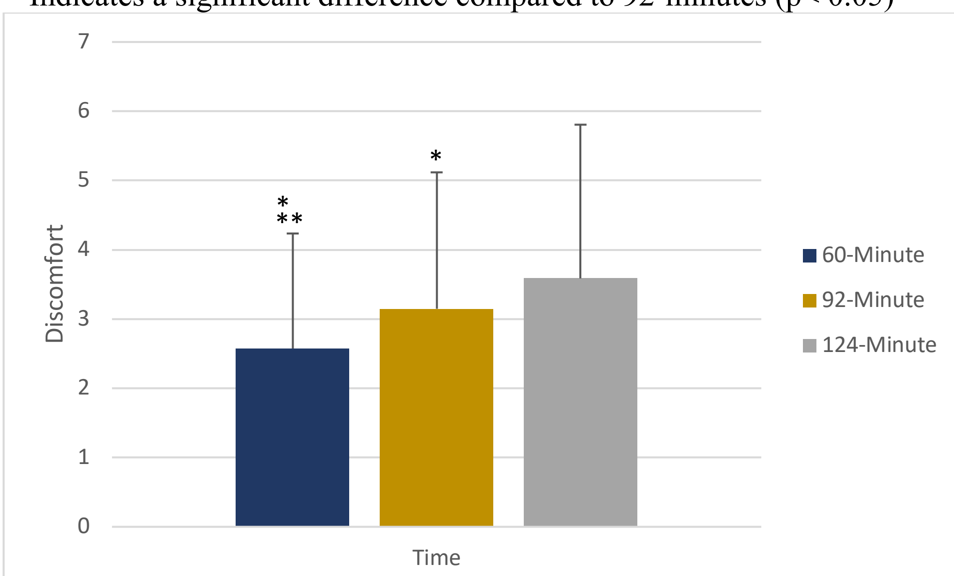



Figure 3.13: Time Effects on Total Body Discomfort
*Indicates a significant difference compared to 124-minutes ($p < 0.05$)
**Indicates a significant difference compared to 92-minutes ($p< 0.05$)




Total Body $SmO_2$ A main effect for trial (p=0.012) was observed for total body $SmO_2$. No main effect for time (p=0.599) was observed. The effect size for time was 0.06, suggesting no effect. Significantly higher $SmO_2$ levels were recorded during the

MCS condition (63.28 ± 18.03) when compared to the NCS condition (55.79 ± 17.54). the effect size between the SCS and NCS conditions was 0.09, suggesting no effect. The effect size between the MCS and SCS conditions was 0.31, suggesting a small effect.

Figure 3.14: Trial Effects on Total Body $SmO_2$
*Indicates a significant difference compared to the NCS condition ($p < 0.05$)

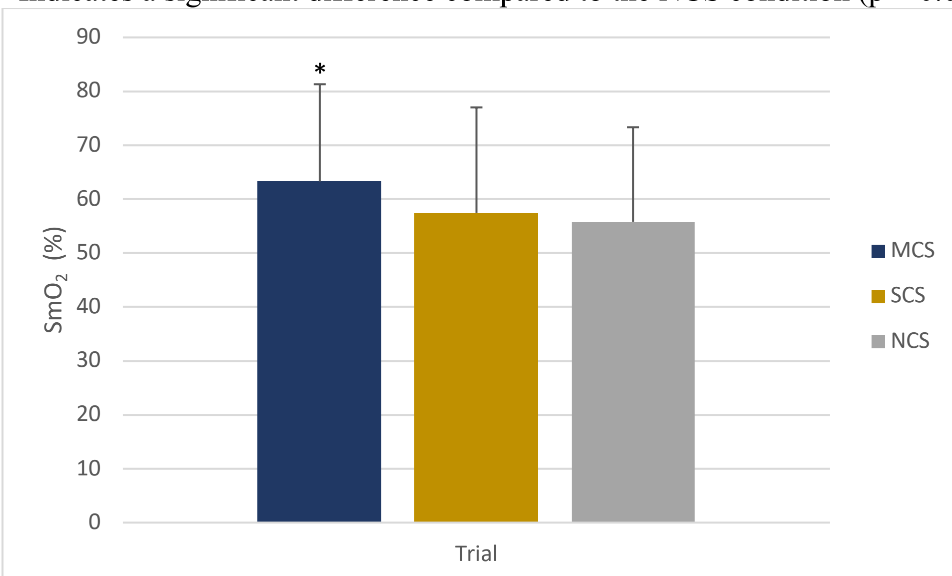
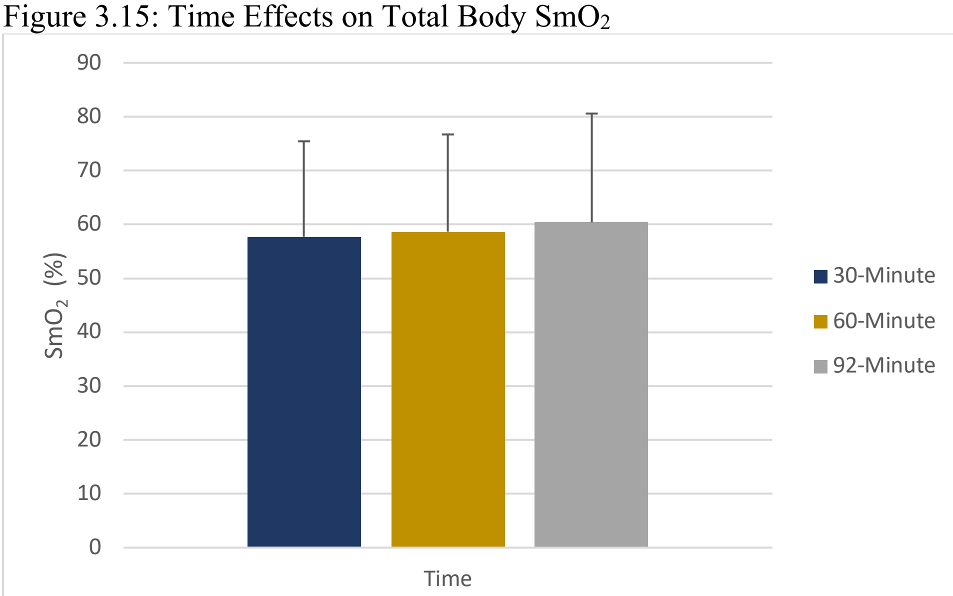


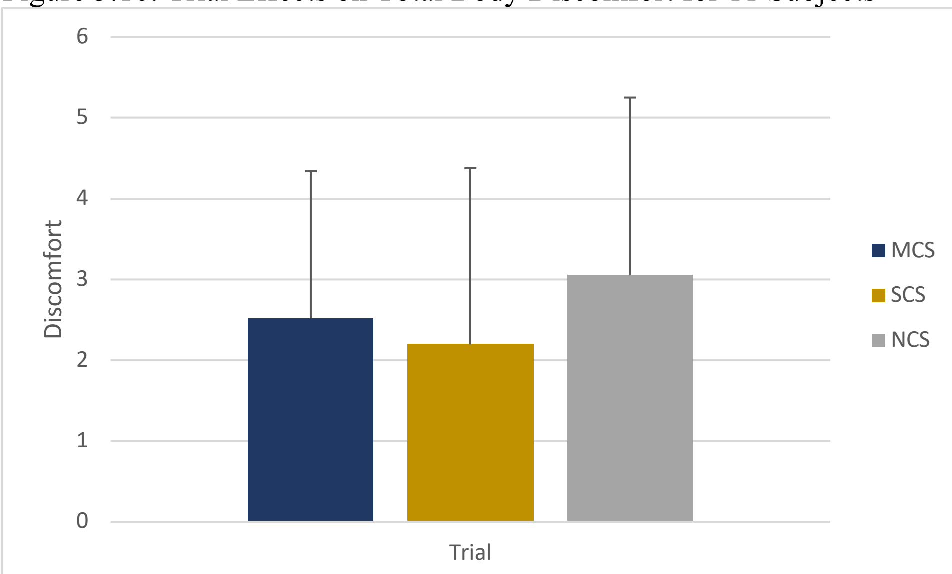

Figure 3.15: Time Effects on Total Body $SmO_2$



Out of the 13 subjects tested, 11 of them were able to make it to the 60-minute mark for all three conditions. This resulted in a sample size reduction from 13 to 11.

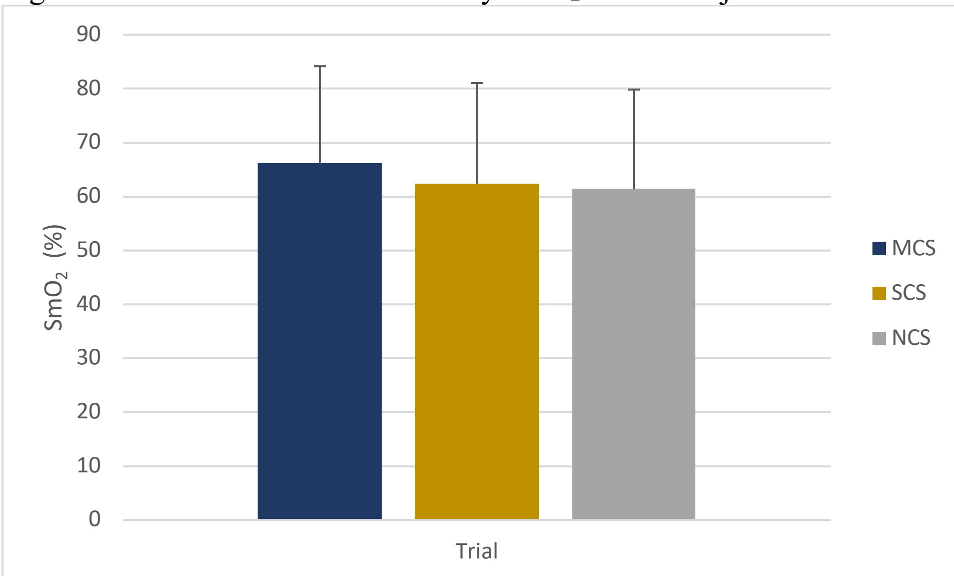
Total Body Discomfort There was no significant trial (p=0.081) main effect observed for total body discomfort. The effect size was 0.19, suggesting a small effect.

Figure 3.16: Trial Effects on Total Body Discomfort for 11 Subjects



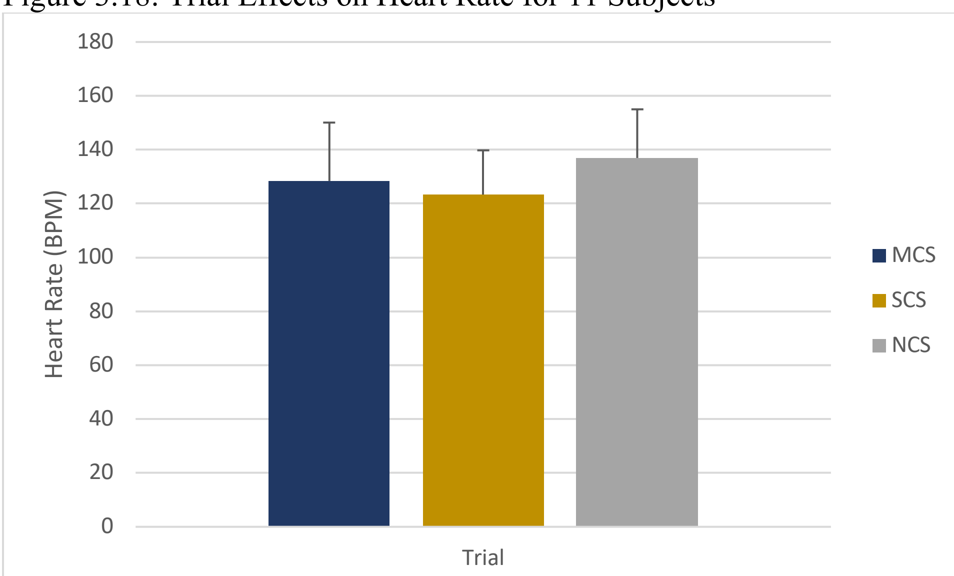

Total Body $SmO_2$ There were no significant trial (p=0.125) main effect observed for total body $SmO_2$. The effect size was 0.14, suggesting a little to no effect.

Figure 17: Trial Effects on Total Body $SmO_2$ for 11 Subjects



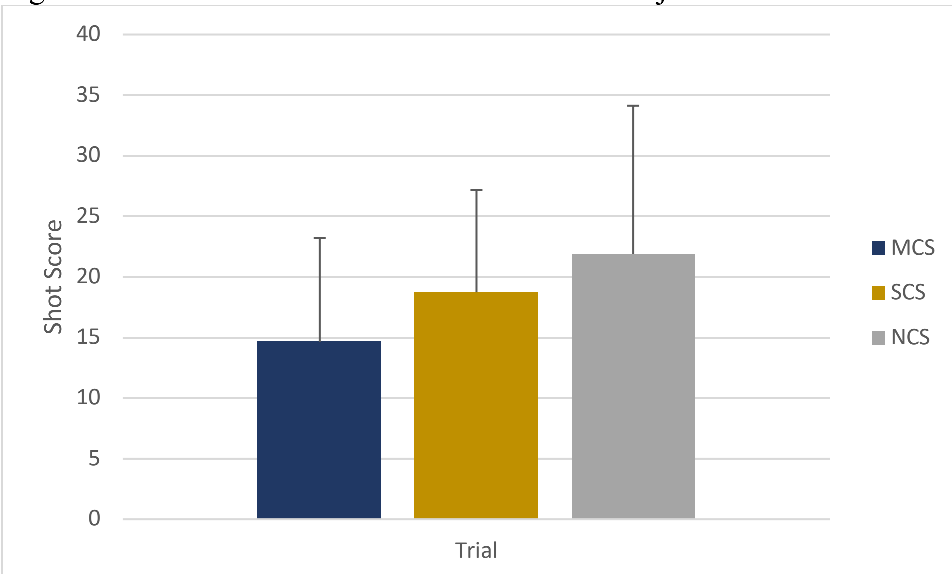

Heart Rate There was no significant main effect of trial ($p=0.083$) for heart rate. the effect size was 0.30, suggesting a medium effect.

Figure 3.18: Trial Effects on Heart Rate for 11 Subjects



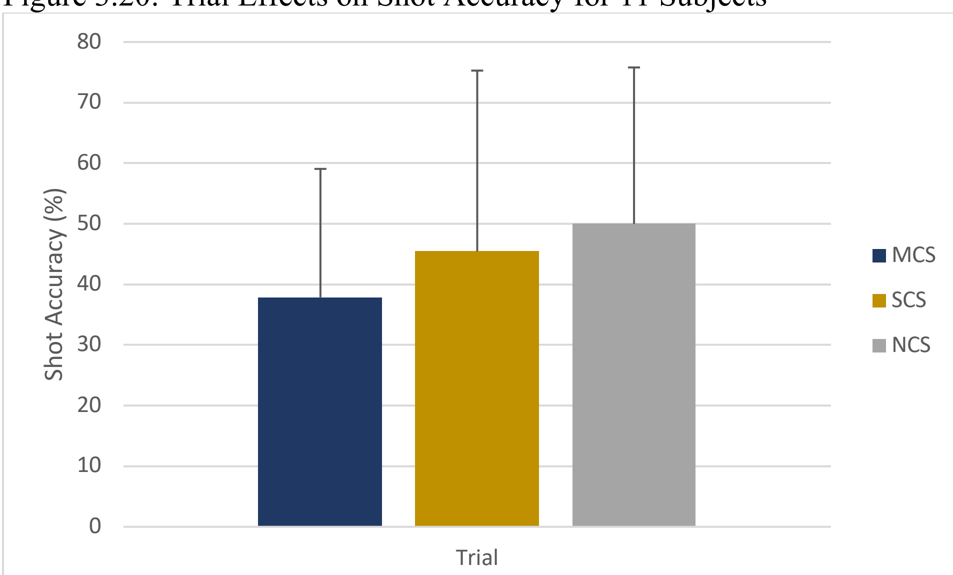

Shot Score There was no significant trial ($p=0.241$) main effect for the shot score the effect size was 0.21, suggesting a small effect.

Figure 3.19: Trial Effects on Shot Score for 11 Subjects




Accuracy There was no significant trial (p=.451) main effect for accuracy. The effect size was 0.11, suggesing no effect.

Figure 3.20: Trial Effects on Shot Accuracy for 11 Subjects



## Discussion

The purpose of this study was to examine how using different chest straps will affect physiological and performance measures during a simulated road march. The analysis was broken into those that completed every march and those that made it to the 60-minute mark. The initial analysis is for seven young, healthy men (M ± SD: 22 ± 3.5y, 24.75 ± 1.38 BMI). All seven men had some sort of military experience prior to testing.

Discomfort for the initial analysis was conducted for the shoulder and upper arm. This upper limb region is where the majority of the shoulder strap pressure is exerted, therefore it should be analyzed for discomfort. Past studies have also found that soldiers report the highest discomfort in the shoulders (Birrell & Hooper, 2007; Bryant et al., 2001). There was no interaction reported between time and chest strap condition. The participants in this study reported significantly greater discomfort when not using a chest strap when compared to the standard strap condition. There were no significant differences when comparing the modified chest strap to the no chest strap or the standard chest strap conditions. There were also significant differences when examining the effect of time. As time went on the subjects reported higher discomfort. There were no significant differences between either chest strap. The analysis was also done by using all discomfort scores collected through the body. The results here also resulted in no interaction between time and chest strap condition. There was, however, significant main effects for time and chest strap condition. In this case, the MCS condition resulted in significantly lower discomfort values than either the SCS or NCS conditions. The time results mirrored the upper limb discomfort where discomfort increased as time increased. These results would suggest that neither chest strap condition results in lower shoulder and upper arm discomfort when compared to each other. However, both chest straps may result in lower discomfort when compared to wearing no chest strap at all. These findings are important as previous research has found that individuals that report higher shoulder discomfort during a march are more likely to drop out before completing the march (Birrell & Hooper, 2007).

The initial analysis of $SmO_2$ was limited to only upper limb values. These results showed that wearing the modified chest strap resulted in higher $SmO_2$ values than either of the other two conditions. This result differs from the Hollins et al. (2013) study as they found no differences in fingertip oxygenation between the three chest strap conditions. This may be because different locations and equipment were used in this study. There were also no differences in oxygenation in the upper extremities as time increased. The analysis of total body $SmO_2$ also resulted in a difference between trials. This time the MCS condition resulted in significantly higher $SmO_2$ values when compared to the NCS condition only. Mirroring the initial analysis, total body $SmO_2$ also had no differences as time increased. These results would suggest that wearing the modified chest strap would result in higher upper limb oxygenation. This is the first study to examine how $SmO_2$ in the upper limb is affected using different chest straps. This could indicate that soldiers may benefit from using the modified chest strap as a higher oxygenation rate would lead to a higher muscular $VO_2$ and increased performance as suggested by Richardson et al. (1999). However, since there was no measure of atrial oxygenation, no direct conclusions can be made since there is no way to tell what the oxygen saturation was prior to entering the capillaries.

Significant differences in heart rate were observed between trials. The MCS and SCS conditions resulted in lower heart rates when compared to the NCS condition. This difference was 9% lower in the chest strap conditions than in the no chest strap condition. This may be an indication that using a chest strap will decrease the energy expenditure of carrying a load. The main purpose of a chest strap is to secure the carrying device to the body. This will cause the backpack to sway with the body instead of on its own. This difference in swaying potential may lead to differences in energy expenditure as body had to counteract the swaying of the backpack.

When examining marksmanship performance of shot score and accuracy there were no differences between times or conditions. This suggests that even though there were physiological differences occurring, the subjects were able to overcome these effects and have similar scores across trials. This may be attributed to the subjects being able to time their shots as the rifle swayed over the target. This would suggest that the use of a chest strap will neither improve nor diminish marksmanship performance. Past studies have shown that marksmanship tends to decrease between baseline and post march shots in both accuracy (Hadid et al., 2017) and precision (Knapik et al., 1997; Tharion & Moore, 1993). This would imply that marksmanship may change from baseline to post march while loaded. However, the results of the current study also suggest that there is no change in marksmanship values at different timepoints during a loaded march.

After the initial analysis was done a secondary analysis using all subjects that completed at least 60-minutes of each trial was done. The results of the 60-minute analysis was that there were no trial effect differences for any variable tested. These results suggest that there were no performance or physiological advantage in using a chest strap or not using one for 60-minutes.

During testing there were multiple sources of error that could have had an impact on the results of this study. Nine of the subjects being tested had previous military experience while four did not. None of the non-military subjects were able to complete the entire protocol for all trials. This would suggest that this protocol is unfit for those that do not have military experience. Another of these errors comes from the population used when trying to get self-reported discomfort. This is due to the training that military members go through in order to prepare them to fight. They are taught to either ignore or push through the pain in order to complete their task. This may result in subjects reporting that they have minimal discomfort when, in reality, they are actually in a lot of discomfort. Until there is a practical way to physiologically determine discomfort this error will continue with this kind of study. Another source of error may have also come with the different rifle experience of the subjects. The initial acclimatization during the first visit attempted to reduce this error. However, coming into the lab and shooting with an unfamiliar rifle or scope a few times will not put the subject on level ground with another subject that has vast experience using a similar rifle or scope.

Another source of error comes from the $SmO_2$ monitors that were used. Unfortunately, there has been no study showing that the device used is validated for measuring $SmO_2$. With this lack of equipment validation, the confidence of the $SmO_2$ results may not be high. The devices were also not able to record throughout an entire march. It was found after testing that the devices would stop recording during the last march. This resulted incomplete $SmO_2$ data sets and the final 30 minutes were not analyzed for those that completed each trial.

The final source of error comes from the study design. Although an initial pilot study was conducted, a follow-up pilot was not done once the protocols were changed. If a second pilot study was completed the intensity of the revised protocol may have been realized prior to testing. The result of the revised protocol was a dropout rate of 46% on at least one trial. This is what prompted the secondary analysis to examine if there were physiological and performance changes at the 60-minute mark for all subjects that completed the first march of each trial.

## Conclusion

In conclusion, the analysis of chest straps would suggest that using the modified chest strap may result in more favorable physiological measures. These physiological measures include decreased discomfort, decreased heart rate and increased muscle oxygenation during a simulated road march. Future studies may want to examine the specific area and force of pressure across the shoulders and chest area while wearing the different chest strap configurations. A further examination of blood flow and muscle saturation should also be reexamined using equipment that has been validated for these measures. Muscle oxygen saturation should also be paired with atrial oxygen saturation. These studies should also investigate only using subjects that have previous military experience as this is the population of interest. With the results suggesting that there may be differences in energy expenditure between chest strap conditions, a biomechanical analysis of backpack sway with each strap condition may reveal if there is truly an energy expenditure difference.

## REFERENCES CITED

American College of Sports Medicine (2010) Health related physical fitness testing and interpretation. In: Thompson WR, Gordon NF, Pescatello LS (Eds) ACSM's guidelines for exercise testing and prescription, 8th ed. Lippincott Williams & Wilkins, Baltimore, pp 60-104.

American College of Sports Medicine (1998) The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc 30: 975 – 991.

Army Field Manual (FM) 21-18 (N.D.) Factors affecting foot marches. Washington, D.C., Headquarters, Department of the Army.

Austin, K. G., Daigle, K. A., Patterson, P., Cowman, J., Chelland, S., & Haymes, E. M. (2005). Reliability of near-infrared spectroscopy for determining muscle oxygen saturation during exercise. *Res Q Exerc Sport, 76*(4), 440-449. doi:10.1080/02701367.2005.10599317

Bastien, G. J., Schepens, B., Willems, P. A., & Heglund, N. C. (2005). Energetics of load carrying in Nepalese porters. *Science, 308*(5729), 1755. doi:10.1126/science.1111513

Bastien, G. J., Willems, P. A., Schepens, B., & Heglund, N. C. (2005). Effect of load and speed on the energetic cost of human walking. *European journal of applied physiology, 94*(1-2), 76-83.

Beekley, M. D., Alt, J., Buckley, C. M., Duffey, M., & Crowder, T. A. (2007). Effects of heavy load carriage during constant-speed, simulated, road marching. *Military medicine, 172*(6), 592-595.

Belardinelli, R., Barstow, T. J., Porszasz, J., & Wasserman, K. (1995). Changes in skeletal muscle oxygenation during incremental exercise measured with near infrared spectroscopy. *European journal of applied physiology and occupational physiology, 70*(6), 487-492. doi:10.1007/bf00634377

Birrell, S. A., & Hooper, R. H. (2007). Initial subjective load carriage injury data collected with interviews and questionnaires. *Military medicine, 172*(3), 306-311.

Bom, F. (1953). A CASE OF "PACK-PALSY" FROM THE KOREAN WAR. *Acta Psychiatrica Scandinavica, 28*(1), 1-4.

Bryant, J. T., Doan, J., Stevenson, J., Pelot, R., & Reid, S. (2001). *Validation of objective based measures and development of a performance-based ranking method for load carriage systems*. Retrieved from

Corkill, G., Lieberman, J. S., & Taylor, R. G. (1980). Pack Palsy in Backpackers. *Western Journal of Medicine, 132*(6), 569.

Crowder, T. A., Beekley, M. D., Sturdivant, R. X., Johnson, C. A., & Lumpkin, A. (2007). Metabolic effects of soldier performance on a simulated graded road march while wearing two functionally equivalent military ensembles. *Military medicine, 172*(6), 596-602.

Dempsey, P. G., Ayoub, M., Bernard, T. M., Endsley, M. R., Karwowski, W., Lin, C. J., & Smith, J. L. (1996). Ergonomic investigation of letter-carrier satchels: Part I. Field study. *Applied Ergonomics, 27*(5), 303-313.

Hadid, A., Katz, I., Haker, T., Zeilig, G., Defrin, R., Epstein, Y., & Gefen, A. (2017). Effect of Load Carriage on Upper Limb Performance. *Medicine and Science in Sports and Exercise, 49*(5), 1006-1014.

Hernandez, L., Alhemood, A., Genaidy, A. M., & Karwowski, W. (2002). Evaluation of different scales for measurement of perceived physical strain during performance of manual tasks. *International Journal of Occupational Safety and Ergonomics, 8*(4), 413-432.

Hollins, J. E. (2012). *The influence of backpack chest straps on physiological and performance variables associated with simulated road marching.* Montana State University-Bozeman, College of Education, Health & Human Development.

Hollins, J. E., Reinking, B. W., Pribanic, K. A., & Heil, D. P. (2013). *Influence of Backpack Chest Straps on Heavy Load Carriage While Wearing an Armored Vest.* Paper presented at the Medicine and Science in Sports and Exercise.

Jones, G. R., & Hooper, R. H. (2005). The effect of single-or multiple-layered garments on interface pressure measured at the backpack-shoulder interface. *Applied Ergonomics, 36*(1), 79-83.

Kim, S. H., Neuschwander, T. B., Macias, B. R., Bachman, L., & Hargens, A. R. (2014). Upper extremity hemodynamics and sensation with backpack loads. *Applied Ergonomics, 45*(3), 608-612.

Knapik, J., Harman, E., & Reynolds, K. (1996). Load carriage using packs: a review of physiological, biomechanical and medical aspects. *Applied Ergonomics, 27*(3), 207-216.

Knapik, J., Kirk, J., Ang, P., Bensel, C., Meiselman, H., Hanlon, W., & Johnson, W. (1997). Soldier performance and strenuous road marching: influence of load mass and load distribution. *Mil Med, 162*, 62-67.

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

Knapik, J., Reynolds, K., Orr, R., & Pope, R. (2016). Load carriage-related paresthesias: Part 1: Rucksack palsy and digitalgia paresthetica. *Journal of Special Operations Medicine, 16*(4), 74.

Legg, S., & Cruz, C. (2004). Effect of single and double strap backpacks on lung function. *Ergonomics, 47*(3), 318-323.

Macias, B. R., Murthy, G., Chambers, H., & Hargens, A. R. (2008). Asymmetric loads and pain associated with backpack carrying by children. *Journal of Pediatric Orthopaedics, 28*(5), 512-517.

Maloiy, G., Heglund, N. C., Prager, L., Cavagna, G. A., & Taylor, C. R. (1986). Energetic cost of carrying loads: have African women discovered an economic way?

Mancini, D. M., Wilson, J. R., Bolinger, L., Li, H., Kendrick, K., Chance, B., & Leigh, J. S. (1994). In vivo magnetic resonance spectroscopy measurement of deoxymyoglobin during exercise in patients with heart failure. Demonstration of abnormal muscle metabolism despite adequate oxygenation. *Circulation, 90*(1), 500-508.

Mao, C. P., Macias, B. R., & Hargens, A. R. (2015). Shoulder skin and muscle hemodynamics during backpack carriage. *Applied Ergonomics, 51*, 80-84.

Maurya, S., Singh, M., Bhandari, P., & Bhatti, T. (2009). Backpack brachial plexus palsy. *The Indian Journal of Neurotrauma, 6*(2), 153-154.

MilitaryMorons. (2009). Mystery Cinch. Mystery Ranch. Retrieved from http://www.militarymorons.com/equipment/mystery/mystery3.html

Nolan, M. F. (1982). Two-point discrimination assessment in the upper limb in young adult men and women. *Physical therapy, 62*(7), 965-969.

Nylund, T., Mattila, V. M., Salmi, T., Pihlajamäki, H. K., & Mäkelä, J. P. (2011). Recovery of brachial plexus lesions resulting from heavy backpack use: A follow-up case series. *BMC musculoskeletal disorders, 12*(1), 62.

Piscione, J., & Gamet, D. (2006). Effect of mechanical compression due to load carrying on shoulder muscle fatigue during sustained isometric arm abduction: an electromyographic study. *European journal of applied physiology, 97*(5), 573-581.

Richardson, R. S., Grassi, B., Gavin, T., Haseler, L., Tagore, K., Roca, J. a., & Wagner, P. (1999). Evidence of O2 supply-dependentV˙ o 2 max in the exercise-trained human quadriceps. *Journal of Applied Physiology, 86*(3), 1048-1053.

Rothner, A. D., Wilbourn, A., & Mercer, R. D. (1975). Rucksack palsy. *Pediatrics, 56*(5), 822-824.

Sagiv, M., Ben-Gal, S., & Ben-Sira, D. (2000). Effects of gradient and load carried on human haemodynamic responses during treadmill walking. *European journal of applied physiology, 83*(1), 47-50.

Stevenson, J. M., Bryant, J. T., Reid, S. A., Pelot, R. P., Morin, E. L., & Bossi, L. L. (2004). Development and assessment of the Canadian personal load carriage system using objective biomechanical measures. *Ergonomics, 47*(12), 1255-1271.

Tharion, W. J., & Moore, R. J. (1993). *Effects of carbohydrate intake and load bearing exercise on rifle marksmanship performance*. Retrieved from

Watson, P. (2016). Rules of thumb on magnitudes of effect sizes. *Retrieved from MRC.*

# APPENDICES

# APPENDIX A

TABLES

Table 1. Demographics (Mean ± SD)

| N | Age | Height (cm) | Weight (kg) | BMI | Military Experience |
|---|---|---|---|---|---|
| 7 | 22 ± 3.5 | 181.86 ± 4.59 | 81.86 ± 5.66 | 24.75 ± 1.38 | 100% |

Table 2. Trial and Time Averages (Mean ± SD)

| Trial or Time | Discomfort | $SmO_2$ | Shot Score | Accuracy | HR |
|---|---|---|---|---|---|
| MCS | 3.506 ± 1.91 | 65.84 ± 17.52 | 14.095 ± 8.82 | 35.681 ± 23.15 | 122.93 ± 18.59 |
| SCS | 3.649 ± 1.91 | 57.87 ± 18.44 | 14.524 ± 11.74 | 34.895 ± 29.29 | 122.58 ± 19.16 |
| NCS | 4.179 ± 2.40 | 56.01 ± 17.89 | 17.429 ± 12.79 | 42.029 ± 30.81 | 134.24 ± 20.48 |
| 30-min | | 58.39 ± 17.30 | | | |
| 60-min | 3.196 ± 1.66 | 59.16 ± 18.10 | 17.190 ± 10.70 | 42.033 ± 23.94 | 125.00 ± 19.48 |
| 92-min | 3.833 ± 1.97 | 62.50 ± 19.69 | 14.143 ± 11.78 | 31.710 ± 25.77 | 124.58 ± 19.57 |
| 124-min | 4.304 ± 2.22 | | 14.714 ± 11.27 | 38.862 ± 32.45 | 128.87 ± 20.89 |

Table 3. Shoulder and Upper Arm Discomfort Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| Discomfort Interaction | 0.820 | .384 | 4 | |
| Discomfort Trial Main Effect | 0.018 | 4.337 | 2 | |
| MCS vs NCS | 0.070 | | | 0.31 |
| SCS vs NCS | 0.027 | | | |
| MCS vs SCS | 1.000 | | | 0.07 |
| Discomfort Time Main Effect | 0.000 | 44.831 | 2 | |
| M3 vs M4 | 0.00 | | | |
| M3 vs M5 | 0.00 | | | |
| M4 vs M5 | 0.00 | | | |

Table 4. Upper Limb $SmO_2$ Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| $SmO_2$ Trial Main Effect | 0.002 | 6.516 | 2 | |
| MCS vs NCS | 0.003 | | | |
| SCS vs NCS | 1.000 | | | 0.10 |
| MCS vs SCS | 0.015 | | | |
| $SmO_2$ Time Main Effect | 0.333 | 1.104 | 2 | 0..12 |

Table 5. Shot Score Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| Shot Interaction Effect | 0.882 | 0.145 | 4 | |
| Shot Trial Main Effect | 0.673 | 0.410 | 2 | 0.17 |
| Shot Time Main Effect | 0.506 | 0.720 | 2 | 0.16 |

Table 6. Accuracy Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| Accuracy Interaction Effect | 0.950 | 0.172 | 4 | |
| Accuracy Trial Main Effect | 0.713 | 1.360 | 2 | 0.16 |
| Accuracy Time Main Effect | 0.293 | 0.348 | 2 | 0.08 |

Table 7. Heart Rate Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| HR Trial Main Effect | 0.017 | 4.232 | 2 | |
| MCS vs NCS | 0.038 | | | |
| SCS vs NCS | 0.033 | | | |
| MCS vs SCS | 1.000 | | | 0.02 |
| HR Time Main Effect | 0.585 | 0.539 | 2 | 0.14 |

Table 8. Total Body Trial and Time Averages for Discomfort and $SmO_2$ (Mean ± SD)

| Trial or Time | Discomfort | $SmO_2$ |
|---|---|---|
| MCS | 2.766 ± 1.79 | 63.28 ± 18.03 |
| SCS | 3.188 ± 1.09 | 57.44 ± 19.58 |
| NCS | 3.356 ± 2.25 | 55.79 ± 17.54 |
| 30-min | | 57.71 ± 17.73 |
| 60-min | 2.575 ± 1.66 | 58.66 ± 18.05 |
| 92-min | 3.148 ± 1.97 | 60.38 ± 20.20 |
| 124-min | 3.586 ± 2.22 | |

Table 9. Total Body Discomfort Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| Discomfort Interaction | .141 | 0.621 | 4 | |
| Discomfort Trial Main Effect | 0.00 | 11.687 | 2 | |
| MCS vs NCS | 0.00 | | | |
| SCS vs NCS | 0.466 | | | 0.10 |
| MCS vs SCS | 0.004 | | | |
| Discomfort Time Main Effect | 0.00 | 99.901 | 2 | |
| M3 vs M4 | 0.00 | | | |
| M3 vs M5 | 0.00 | | | |
| M4 vs M5 | 0.00 | | | |

Table 10. $SmO_2$ Total Body Analysis

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| $SmO_2$ Trial Main Effect | 0.012 | 4.452 | 2 | |
| MCS vs NCS | 0.016 | | | |
| SCS vs NCS | 1.000 | | | 0.09 |
| MCS vs SCS | 0.075 | | | 0.31 |
| $SmO_2$ Time Main Effect | 0.599 | | 2 | 0.06 |

Table 11. Demographics for 11 Subjects (Mean ± SD)

| N | Age | Height (cm) | Weight (kg) | BMI | Military Experience |
|---|---|---|---|---|---|
| 11 | 21 ± 82 | 180.97 ± 6.58 | 81.97 ± 7.22 | 25.03 ± 1.89 | 82% |

Table 12. Trial Time and Averages for 11 Subjects (Mean ± SD)

| Trial | Discomfort | $SmO_2$ | Shot Score | Accuracy | HR |
|---|---|---|---|---|---|
| MCS | 2.519 ± 1.82 | 66.12 ± 18.06 | 14.64 ± 8.57 | 37.86 ± 21.20 | 128.41 ± 21.670 |
| SCS | 2.196 ± 2.18 | 62.39 ± 18.66 | 18.73 ± 8.43 | 45.44 ± 29.84 | 123.32 ± 16.456 |
| NCS | 3.051 ± 2.20 | 61.35 ± 18.50 | 21.91 ± 12.22 | 49.97 ± 25.83 | 136.94 ± 18.067 |

Table 13. Analysis for 11 Subjects

| Variable | P | F | df | Effect Size |
|---|---|---|---|---|
| Discomfort Trial Main Effect | 0.081 | 9.581 | 2 | 0.19 |
| $SmO_2$ Trial Main Effect | 0.125 | 2.118 | 2 | 0.14 |
| Shot Trial Main Effect | 0.241 | 1.493 | 2 | 0.21 |
| Accuracy Trial Main Effect | 0.451 | 0.819 | 2 | 0.11 |
| HR Trial Main Effect | 0.083 | 2.592 | 2 | 0.30 |

# APPENDIX B

## INFORMED CONSENT

**SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH**
**MONTANA STATE UNIVERSITY - BOZEMAN**

**PROJECT TITLE:** **Effects of Backpack Chest Straps on Simulated Shooting Performance Following Repeated Bouts of Treadmill Marching**

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**PURPOSE OF STUDY:**
According to the research literature, extended bouts of marching while carrying a heavy backpack load can cause extreme hand, arm, and shoulder discomfort. Anecdotally, these problems can be amplified (made worse) when the same pack is worn on top of upper body armor, as is standard practice for many military personnel. The use of the backpack's chest strap may alleviate some of this discomfort, but not all people use the chest strap, or use it consistently, so the impact of using a chest strap of any kind on alleviating these symptoms is not known.

*You are being asked to participate* in a study that will compare the use of three back chest strap conditions: 1) No chest strap (NCS); 2) the backpack's own standard chest strap (SCS); 3) an after-market commercially available chest strap (MRC). An armored vest and backpack, as well as an M4-style airsoft rifle fitted with a laser targeting system, will be worn and carried (72.6 lb total), respectively, during each testing with a different chest strap condition tested during each lab visit. We hope to discover whether these three chest strap conditions differ with regard to self-reported measures of discomfort of the hands, arms, and shoulders, as well as how measures of simulated shooting performance may alter repeated bouts of treadmill marching. This information may be helpful to determining how backpacks over armor should be worn in field settings to improve comfort and/or shooting performance.

Prior to testing, each study volunteer is given an Informed Consent Document that explains the purpose of the study, along with the expected risks and benefits of participation. Each volunteer will be screened using the responses provided in a *Health History Questionnaire* (HHQ). The Primary Investigator reserves the right to request that any participant receive documented medical clearance prior to testing if indicated by responses on the HHQ. These procedures are in compliance with policies formulated by the American College of Sports Medicine[1]. Finally, each participant should be physically fit enough to easily perform 120 minutes of treadmill marching at 3 mph. Ideally, you should also have recent experience (previous 3 months) with carrying and/or hiking with heavy loads (e.g., 60+ lbs).

**STUDY PROCEDURES:** If you agree to participate, you will be asked to make four visits to the Movement Science / Human Performance Laboratory (MSL) at Montana State University (basement of Romney Gym). All visits should occur within a 3-week period. The first lab visit will get you acquainted with the testing procedures to be used during testing visits (Visits #2-#4), as well as given a shooting proficiency test

Lab Visit #1. During the first lab visit (about 60 mins), you will read and sign an approved consent document, fill out a health history questionnaire, practice wearing both the upper body armor and backpack, as well as practice using the laser-based rifle for indoor target practice. After practicing the procedures for treadmill walking with the armor, backpack, and rifle, you will practice target shooting with a target that is approximately 30 ft away. As a laser-based targeting system, the rifle is designed to give a loud "pop" noise (similar to a rifle firing) with every shot, but no projectiles are actually being fired. The popping noise is used to add a sense of realism when using the rifle. Once you feel comfortable using the rifle and target system, you will be given a *shooting proficiency test* which will serve as a baseline, or a standard, for comparison to shooting performance during testing. The

[1] American College of Sports Medicine (2017). *ACSM's Guidelines for Exercise Testing and Prescription* (10th edition). Williams & Wilkins Philadelphia, Pa.

shooting proficiency testing involves standing in place while wearing the armor and backpack and holding the rifle in the "ready" position (barrel pointing downward with hands placed to take aim quickly). While in this position, you are waiting for one of two rotating targets to spin and face you from about 30 ft away. You will then raise the rifle, take aim and hold the target in sight for 4-5 secs, and then fire 5 individual shots in rapid succession before returning the rifle to the ready position. This sequence will be repeated two more times before your lab visit is completed. Your next lab visit will be scheduled to occur with 1-7 days.

Lab Visit #2. During this visit, which will last about 135 mins, you will be asked to complete three separate target shooting trials during a two hour treadmill marching trial while wearing armor, a backpack, and carrying an airsoft rifle. In addition, your first visit will be randomly assigned to one of the three chest strap condition: NCS, SCS, or MRC. You will be asked to arrive at the lab ready for loaded treadmill walking exercise which should include wearing appropriate exercise clothing (shorts, t-shirt) and footwear (good running or hiking shoes, or hiking boots), as well as refraining from exercise 24 hours prior to testing. We will also ask that you plan to eat and drink before the lab visit as if you were going to do an hour of moderate-intensity aerobic exercise, though we will not ask you to document any of this. While bottled water will be provided to you at the end of this visit, please feel free to bring along whatever food and drink that you may want for after testing.

Once at the lab and dressed for exercise, you will be measured for body weight and height, as well as asked your age. Next, you will be prepped with measuring equipment which includes: 1) Chest strap for monitoring heart rate, Muscle oximeters attached (with adhesive wrap) to the outer surface of upper arm and forearm of both arms, as well as the surface of the thigh and calf muscles on the left leg. The oximeters use an infrared beam to detect the amount of oxygen within the capillaries of muscles below the skin surface and we expect that these values will change *during* each lab visit, as well as *between* the three testing visits. Next, you will begin 60 mins of treadmill walking while wearing the armor and backpack and holding the rifle in the ready position. The treadmill speed will start at 2.5 MPH for the first 5 mins (which serves as a warm-up), then increase to 3.0 MPH for the remaining 55 mins. During this 60-min walk you are asked to maintain a steady upper body position and to hold the rifle consistently in the ready position with as little fidgeting of the hands, arms, and shoulders as possible. To help pass the time during while treadmill marching, you will be able to watch anything you want from either Netflix or Hulu on a large TV screen directly in front of the treadmill. At 58 mins into the 60-min walk, the TV will be paused and you will be asked to describe the level of discomfort you feel at specific body locations which will include: Fingers, hands, forearms, upper arms, shoulders, upper back, mid-back, lower back, thighs (upper leg), and lower legs. For each part of the body, you will be asked to give a "discomfort" rating from a scale ranging from a low of "0" (Absolute no discomfort whatsoever), a mid-point of "5" (Strong discomfort), and a high point of "10" (Maximum discomfort).

At the end of 60 mins of marching, the treadmill will stop and you will be asked to turn around completely (a 180° turn), walk to the end of the treadmill and then stand in the ready position. When you hear one of the two targets rotating, you will take aim as quickly as possible and hold the aim for 5 secs before firing a single shot. The rifle then goes back into the ready position for another 30-45 secs before the sequence is repeated a second time, and then a third time. Within 3-4 mins of the treadmill stopping, you will begin the next 30 mins of treadmill marching at 3.0 MPH. At 28 mins into the march, you will rate your discomfort again (same scale and same body locations). After 30-mins of treadmill marching, you will repeat the same shooting sequence described earlier before continuing to the last 30-min marching bout and third shooting sequence. The marching bouts are organized in this way because we are expecting measures of heart rate, muscle oxygenation, body discomfort, and shooting performance to change across the three treadmill walking bouts.

Your next two visits, which cannot be scheduled sooner than 48 hrs after the previous visit, will be the exact same testing procedures except that one of the other three chest strap conditions will be evaluated (i.e., NCS, SCS, MRC).

**POTENTIAL RISKS:** There are several potential risks worth noting for this study. First, treadmill walking of any kind presents a small potential for injury because of the possibility of falling, or tripping, while testing. To minimize this potential for injury, we will do the following: 1) Provide instructions about treadmill walking (during each visit) both before and during each bout of treadmill walking; 2) In the unlikely event of a fall while treadmill walking, there are several 12 inch crash pads located directly behind the treadmill that are used to damped the impact of a fall (i.e., standard procedure for any treadmill testing). In addition, there is always a risk of injury associated with carrying a heavy load, such as to the low back. In order to minimize the risk for injury during lab testing, only those who are experienced with carrying heavy loads will be recruited. In addition, the armor and backpack will be fit as well as possible to each individual, and researchers will always assist with putting on and taking off of the armor and backpack for each lab visit. Finally, there is a chance that you will experience very localize discomfort in the hands, arms and/or shoulders of one or both arms during testing. Based upon pilot testing, we expect that any such discomfort may linger for another 24 hrs after testing and completely gone with 36 hrs. All possible precautions will be taken to ensure your safety, as well as ensure that you feel informed and comfortable with all planned testing before any testing takes place. Of course, you are always encouraged to inform the investigators of any discomfort associated with any aspect of the testing.

**SUBJECT COMPENSATION:**
Upon completion of the second, third, and fourth study visits, you will be given several different types of compensation. Following completion of the second lab visit, you will be given a t-shirt ($20 market value) from a local backpack company in a size of your choice. Following completion of the third lab visit, you will be given $20 cash. Finally, following the fourth and last lab visit, you will be given a gift certificate for $150 from the same local backpack company to use toward the purchase of any of their regularly priced shop merchandise. Finally, you may also request a copy of publications or presentations that will result from this project by contacting the primary investigator, Dan Heil (dheil@montana.edu; 406-994-6324).

**BENEFITS:** There are no direct benefits to you as a volunteer for this study.

**CONFIDENTIALITY:**
The data and personal information obtained from this study will be regarded as privileged and confidential with only the Project Director and research assistant having access to this information. Your right to privacy will be maintained in any ensuing analysis and/or presentation of the data by using coded identifications of each person's data. The self-reported that you provide on the Health History Questionnaire will be retained within a locked cabinet in our lab for 7 years (as required by MSU), after which the document will be destroyed by paper shredding.

**FREEDOM OF CONSENT:**
You may stop testing at any time, or withdraw consent for participation in writing, by telephone or in person without prejudice or loss of benefits (as described above). *Participation is completely voluntary.*

In the UNLIKELY event that your participation in the study results in physical injury to you, the Project Director will advise and assist you in receiving medical treatment. No compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of your participation in this study. Additionally, no compensation is available from Montana State University for injury, accidents, or expenses that may occur as a result of traveling to and from your appointments at the Movement Science / Human Performance Laboratory. *Further information regarding medical treatment may be obtained by contacting the Project Director, Dan Heil (dheil@montana.edu; 406-994-6324).* You are encouraged to express any questions, doubts or concerns regarding this study. The Project Director will attempt to answer all questions to the best of her ability prior to any testing. The Project Director fully intends to conduct the study with your best interest, safety and comfort in mind. *Additional questions about the rights of human subjects can be answered by the Chairman of the Human Subjects Committee, Mark Quinn, at 406-994-4707, or by email (mquinn@montana.edu).*

**PROJECT TITLE: Effects of Backpack Chest Straps on Simulated Shooting Performance Following Repeated Bouts of Treadmill Marching**

## STATEMENT OF AUTHORIZATION

I, *the participant*, have read the Informed Consent Document and understand the discomforts, inconvenience, risks, and benefits of this project. I, ______________________________ *(print your name)*, agree to participate in the project described in the preceding pages. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent form for my own records.

**Signed:**______________________________ **Age** _______ **Date**___________

***Subject's Signature***

In addition, we would like to take photographs during some testing sessions for use in professional presentations at conferences. Photos will not be taken during all test sessions, or even for all volunteers, but rather a sample of volunteers who provide their consent. Please indicate below whether you give your permission for such photographs during testing.

**Please *initial* one of the following:**

☐ I give permission for photographs to be taken of me during this project with the understanding that these photographs may be used in professional presentations.

☐ I DO NOT give permission for photographs to be taken of me during this project.

**Signed:**______________________________ **Date**___________

***Investigator***

APPROVED
MSU IRB
02/14/2018
Date approved

# APPENDIX C

## HEALTH HISTORY QUESTIONNAIRE

# Health History Questionnaire (HHQ) - Montana State University

# Movement Science/Human Performance Laboratory

## INSTRUCTIONS

Complete each of the following questions as accurately as possible by filling in the blanks or checking the most appropriate box. All information provided is confidential and no information will be released without your written consent.

*Today's Date* ________________

## GENERAL INFORMATION

*Mr.* ☐ *Ms.* ☐ *Miss* ☐ *Mrs.* ☐ *Dr.* ☐

*Last Name* ________________________ *First Name* ______________________

*Mailing Address* __________________________________________________

__________________________________________________

*Home Phone* _______________________ *Office Phone* _____________________

*Occupation* _______________________________________________________

*Employer* _______________________________________________________

*Person to Contact in Emergency:* *Name* ________________________________

*Relationship* ___________________________

*Phone* __________________________

◆ *Descriptive information:*

*Gender: Male* ☐ *Female* ☐

*Body Weight* _____________ *Body Height* ______________

*Age* _______ *Date of Birth* ___________

◆ *Why are you filling out this questionnaire?*

☐ *You have volunteered for a research study or project?*

☐ *You are being screened for fitness testing in the Movement Science Lab?*

☐ *Other reason...*__________________________________________________

**MEDICAL HISTORY**

---

*Name of your physician* ______________________________

*(Address/phone?)* ______________________________

- *Family History:*

  *Did your father, or other first degree male relative (like a brother) die before the age of 55?*

  *No* ☐ *Yes* ☐ *If "Yes", cause?*

  ______________________

  *Age at death?* ______________________

  *Which relative?* ______________________

  *Did your mother, or other first degree female relative (like a sister) die before the age of 65?*

  *No* ☐ *Yes* ☐ *If "Yes", cause?*

  ______________________

  *Age at death?* ______________________

  *Which relative?* ______________________

- *List any food or drug allergies:* ______________________________

  ______________________________

  ______________________________

  ______________________________

◆ *List any medication you are currently taking (non-prescription and prescription, including oral contraceptives). Please comment on the reason for each medication.*

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

◆ *Please describe any recent illnesses, hospitalizations, or surgical procedures:*

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

◆ *Any of these health symptoms that occurs frequently (ranked as either a 4 or 5 below), either at rest or during physical exertion, is the basis for a prompt medical evaluation. Circle the number indicating how often you have each of the following:*

***0*** *= Never* ***1*** *= Practically never* ***2*** *= Infrequently* ***3*** *= Sometimes*

***4*** *= Fairly often* ***5*** *= Very often*

*a. Coughing up blood. 0 1 2 3 4 5*

*b. Abdominal pain. 0 1 2 3 4 5*

*c. Low-back pain. 0 1 2 3 4 5*

*d. Chest pain. 0 1 2 3 4 5*

*e. Neck, jaw, arm, or shoulder pain. 0 1 2 3 4 5*

*f. Leg pain. 0 1 2 3 4 5*

*g. Swollen joints, especially the ankles. 0 1 2 3 4 5*

*h. Feel faint. 0 1 2 3 4 5*

*i. Feeling of dizziness. 0 1 2 3 4 5*

*j. Breathless with slight exertion. 0 1 2 3 4 5*

*k. Palpitation or fast heart rate. 0 1 2 3 4 5*

*l. Unusual fatigue with normal activity. 0 1 2 3 4 5*

*m. Abnormal/labored breathing at night. 0 1 2 3 4 5*

*For any score of "4" or higher, use the space below to explain the frequency and the conditions under which you experience that particular symptom:*

◆ *Please indicate which of the following for which **you have been diagnosed or treated** by a physician or health professional. Please be as complete as possible.*

*Check if "Yes" If "Yes", please comment further...*

---

- ☐ *Alcoholism* ______________________________
- ☐ *Anemia, sickle cell* ______________________________
- ☐ *Anemia, other* ______________________________
- ☐ *Asthma* ______________________________
- ☐ *Back strain* ______________________________
- ☐ *Blood pressure - High?* ______________________________
  *Low?* ______________________________
- ☐ *Bronchitis* ______________________________
- ☐ *Cancer* ______________________________
- ☐ *Cirrhosis, liver* ______________________________
- ☐ *Cholesterol - High?* ______________________________
- ☐ *Concussion* ______________________________
- ☐ *Congenital defect* ______________________________
- ☐ *Diabetes* *Type?*______________________________
- ☐ *Emphysema* ______________________________
- ☐ *Epilepsy* ______________________________
- ☐ *Eye problems* ______________________________
- ☐ *Gout* ______________________________
- ☐ *Hearing loss* ______________________________
- ☐ *Heart problems* ______________________________
- ☐ *Hypoglycemia* ______________________________
- ☐ *Hyperlipidemia* ______________________________
- ☐ *Infectious mononucleosis* ______________________________
- ☐ *Kidney problems* ______________________________

- ☐ *Menstrual irregularities* ____________________
- ☐ *Mental illness* ____________________
- ☐ *Neck stain* ____________________
- ☐ *Obesity* ____________________
- ☐ *Phlebitis* ____________________
- ☐ *Rheumatoid arthritis* ____________________
- ☐ *Stroke* ____________________
- ☐ *Thyroid problems* ____________________
- ☐ *Ulcer* ____________________
- ☐ *Other* ____________________

____________________

____________________

## BLOOD CHEMISTRY PROFILE

- *Have you ever had a fasting blood sample analyzed for cholesterol?* ☐ *Yes* ☐ *No*

*If "Yes", when was last time your blood was analyzed?* ____________________

*If "Yes", please provide as much detail as possible with regard to the specific blood components requested below (most recent test results only). Ideally, we would like both the numerical value of the test result AND the units of the measurement (the units are typically reported along with the numerical value of the test result).*

✓ *Total serum cholesterol* __________ *units?*__________

✓ *HDL (high density lipoprotein)*__________ *units?* __________

✓ *LDL (low density lipoprotein)*__________ *units?* __________

✓ *VLDL (very low density lipoprotein)*__________ *units?* __________

✓ *Triglycerides*__________ *units?* __________

✓ *Blood glucose*__________ *units?* __________

✓ *Hemoglobin*__________ *units?* __________

✓ *Hematocrit*__________ *units?* __________

✓ *Iron*__________ *units?* __________

**HEALTH-RELATED BEHAVIORS**

---

- *Do you now smoke?* ☐ *Yes* ☐ *Infrequently* ☐ *No*

  *If "Yes" or "Infrequently", indicate the number smoked per day (on average):*

  *Cigarettes: 40 or more 20-39 10-19 1-9*

  *Cigars/pipes - describe:*________________________________________

- *Have you recently quit smoking?* ☐ *Yes* ☐ *No*

  *If "Yes", how long ago did you quit?* _______ *years* ________ *months*

- *Do you currently work in an environment where smoking is allowed?*

  ☐ *Yes* ☐ *No*

  *If "Yes", where do you work AND how frequently do you work in this environment?*

- *Do you drink alcoholic beverages on a regular basis?* ☐ *Yes* ☐ *No*

*(i.e. at least once/week)*

*If "Yes", please answer the following:*

*1) How frequently do you drink?*

*2) What alcoholic beverages do you typically consume?*

◆ *Have you **exercised** regularly in the past 4 weeks?* ☐ *Yes* ☐ *No*

*If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:*

◆ *Do you consider yourself **physically active** due to work-related demands, home or farm chores, etc.?* ☐ *Yes* ☐ *No*

*If "Yes", describe in terms of frequency, duration, intensity, and type of exercise:*

◆ *Please describe anything not already described on this questionnaire that might cause you problems during exercise (use the space below).*

◆ *Are there any other health-related problems or concerns NOT addressed on this questionnaire that we should know about?*

☐ *Yes* ☐ *No* *If “Yes”, please describe below:*

# APPENDIX D

## DISCOMFORT RATING SCALE

# Discomfort Rating Scale

| | |
|---|---|
| **0** | **No discomfort whatsoever.** |
| **0.5** | **Just noticeable discomfort.** |
| **1** | |
| **2** | **Light discomfort.** |
| **3** | **Moderate discomfort.** |
| **4** | |
| **5** | **Strong discomfort.** |
| **6** | |
| **7** | |
| **8** | **Severe discomfort.** |
| **9** | |
| **10** | **Maximum discomfort – i.e., activity must stop because discomfort is so bad.** |

***Discomfort*** is defined as… irritation, soreness, or pain that can vary from lightly annoying to severely painful.