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**MUSCLE SORENESS AND DAMAGE DURING WILDLAND FIREFIGHTER CRITICAL
TRAINING**

By

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Thesis Paper

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Muscle Soreness and Damage During Wildland Firefighter Critical Training

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Introduction: Wildland firefighters (WLFFs) undergo a critical training (CT) period immediately before the firefighting season. The intensity of CT exercise could lead to muscle damage, as previously reported cases of rhabdomyolysis in WLFFs have been documented. This study established the effects of activities performed during a two-week CT period on acute markers of muscle damage in WLFFs.

Methods: 18 male and 3 female Type I Interagency Hotshot WLFFs were studied during a 14-day critical training period. Upper- (US) and lower-body (LS) muscle soreness and daily body weight (BW) scales were collected. Venous blood was collected on Days 1, 4, 8, and 11 to measure markers of muscle damage (creatine kinase, lactate dehydrogenase, c-reactive protein) and overtraining (cortisol, testosterone). Skinfold measurements were taken on Days 1 and 11 to calculate body fat (BF) and lean body weight (LBW). The BLM fitness challenge defined fitness.

Results: No differences in body weight were observed Days 1-11 ($p=0.065$). BF significantly decreased from Day 1 to 11 ($15.3\pm 1.4\%$ vs. $14.1\pm 1.3\%$, $p=0.002$), while LBM significantly increased ($67.3\pm 2.3\text{kg}$ vs. $68.8\pm 2.2\text{kg}$, $p=0.002$). US and LS showed main effects of time, elevated from baseline for subsequent days, peaking on Day 3 (US: $3.8\pm 0.5\text{ cm}$, $p<0.001$; LS: $4.3\pm 0.3\text{ cm}$, $p<0.001$). CK showed a significant effect of time, elevated from baseline, peaking on Day 4 ($73.4\pm 14.4\text{ U}\cdot\text{L}^{-1}$ vs. $132.8\pm 15.4\text{ U}\cdot\text{L}^{-1}$, $p=0.001$). LDH showed a significant effect of time, where Day 11 significantly increased from Day 1 ($159.4\pm 5.5\text{ IU}\cdot\text{L}^{-1}$ vs. $164.4\pm 6.9\text{ IU}\cdot\text{L}^{-1}$, $p=0.04$). There was no significant difference in CRP ($p=0.32$). There was a significant increase in cortisol on Day 8 ($48.0\pm 4.6\text{ ng}\cdot\text{mL}^{-1}$ vs. $61.9\pm 2.9\text{ ng}\cdot\text{mL}^{-1}$, $p=0.036$), while no difference was seen in testosterone ($p=0.25$). The testosterone/cortisol ratio showed a significant decrease on Day 8 (0.31 ± 0.05 vs. 0.19 ± 0.02 , $p=0.014$). Elevated fitness and off-season training habits correlated with ameliorations in these markers.

Conclusion: These data suggest that WLFFs undergo significant physiological stressors resulting in muscle soreness, damage, and overtraining during CT. Fitness and preparedness appear to have a protective effect on the strain experienced from the training stimulus. Careful preparation and monitoring of the training stimulus are vital to avoid clinical ramifications.

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CHAPTER ONE: INTRODUCTION

Introduction

Wildland firefighting is a demanding occupation that involves strenuous activity for extended periods in a frequently hot environment. The high physical demands are exacerbated by stresses from heat, wood smoke exposure, personal protective equipment, and hydration limitations ^{1,2}. Because of this, wildland firefighters (WLFF) can undergo extreme physiologic stress ³.

These stressors pose unique physiologic occupational challenges for WLFF. Due to the extensive physical requirements, their daily energy expenditures are often much higher than those of individuals in typical sedentary occupations ^{4,5}. The various occupation-specific tasks present throughout a typical WLFF shift produce variant energy expenditures, with ingress hikes resulting in the highest energy expenditure. At the same time, basecamp logistics revealed similar expenditure to baseline values ⁶. Maintaining adequate performance is challenging for WLFFs due to prolonged physical activity, wearing personal protective equipment, and exposure to high temperatures ⁴. Uncompensable heat stress can result from these challenges when the body's cooling requirements exceed the environmental capacity to cool ⁷. Additionally, acute and chronic wood smoke inhalation can result in increased incidences of asthma, bronchitis, and other upper respiratory tract issues, as well as promote systemic oxidative stress, potentially compromising physiologic function ⁸. Intense training, education, and monitoring of the WLFF are required to address the above factors to ensure efficacy and safety during field operations.

WLFF must overcome these physiological challenges to be successful in their duties, and they must maintain their health throughout the entire fire season. The length of the fire season in the United States depends on the local drought conditions each year, but across the western US, the number and severity of fires are consistently increasing as an annual trend⁹. With this growing challenge, occupational injuries among WLFFs are common. Injuries vary in type and severity and include muscle and joint strains, trauma injuries, heat-related illnesses, and fractures¹⁰. While examining WLFF injuries between 2003 and 2007, Britton et al. found that 28% of all injuries on the job occurred at the beginning of the season (January-June)¹¹. Likely due to inadequate preparation for the unaccustomed exercise, this can be debilitating for the entire fire season. In a retrospective study looking at injuries from 360 WLFFs, over 20% of injuries that occurred during physical training were perceived as preventable, mostly including muscle strains and other overexertion injuries¹⁰.

To prepare WLFFs for the oncoming stressors and to prevent injuries, a training period is in place; this is usually a two-week period called “critical training” (CT). CT is an operational preparedness time completed by every fire crew/resource to allow each to meet mission objectives and address operational standards¹². Different WLFF crews undergo trainings variable in rigor and intensity, although all WLFFs must complete the arduous pack test. To bolster WLFF preparedness, other benchmark tests that are not required include push-ups, chin-ups, sit-ups, and a 1.5-mile run. Concurrently, crews complete prescribed burns to practice occupational specific techniques and training hikes to improve fitness¹³. For Interagency Hotshot Crews (IHC), completion of this critical 80-hour training period is required to be listed as a Type I fire crew. Moreover,

CT must be completed before assignment on a national incident, a fact that may hold influence over the physiologic strain imposed on WLFF during the 80-hour period ¹².

Though CT is necessary to ensure adequate physical readiness, the initiation of a novel exercise stressor can be harmful following an off-season period. Previous research has shown that the abrupt introduction of unaccustomed, strenuous, or eccentric exercise can damage muscle tissue ¹⁴. Damage is discernible with muscle soreness, swelling, and a loss of force production ¹⁵. From the perspective of muscle architecture, this exercise can result in weakened sarcomeres, leading to leaky membranes, allowing intracellular proteins to leak into the bloodstream. Damage may be quantified through histology and ultrasound. Indirectly, plasma creatine kinase, lactate dehydrogenase, and myoglobin (intracellular proteins located within myocytes) are markers of muscle damage ^{16,17}. While small-scale damage caused by micro-tears can be beneficial and allow for muscular adaptations, extensive damage can result in myocyte necrosis, delayed onset muscle soreness (DOMS), and perhaps the clinical condition of rhabdomyolysis ^{15,18,19}.

Rhabdomyolysis is a clinical syndrome characterized by extreme skeletal muscle cell breakdown, allowing the efflux of intracellular components into blood circulation, which can result in myoglobinuria, electrolyte imbalances, and acute kidney injuries ¹⁹. This clinical condition can be caused by direct muscle injury, muscle ischemia, extreme temperature, electrolyte abnormalities, and drugs. However, extreme exertion causes ~26,000 cases of exertional rhabdomyolysis every year ²⁰. High degrees of muscle damage is common in high-intensity occupations, with military surveillance reporting ~42 cases per 100,000 individuals, and overall higher rates among young males ²¹.

However, it is probable that cases of rhabdomyolysis are underreported, especially in fields that demand excellent physical performance, such as the military or WLFFs. From 2008-2016, there were 26 confirmed cases of rhabdomyolysis in WLFFs, with potential additional cases unreported ²². A large portion of these cases occurred between March and May, indicating an association with the initiation of radical, task-specific exercises. In 2016, three of the six cases reported happened on the first day of training. In the 2019 fire season alone, there were three cases of rhabdomyolysis reported, all occurring during physical training, two of which took place during the standard arduous pack test ²³.

Problem

CT is a necessary, early-season component of the WLFF occupation to prepare individuals for the stressors of the season. However, a significant focus of CT is to introduce physical activity that is task-specific, though WLFF might be unaccustomed to the activity since many have been furloughed since the end of the previous fire season. Though CT is crucial, little research has been conducted regarding the physiological stress exhibited during the CT period for WLFFs. To better aid in the preparation for the fire season and prevent potential injury, it is necessary to understand the acute responses to the intense physical stimuli during CT.

Purpose

The purpose of this investigation is to establish the effects of activities performed during a two-week critical training period on acute markers of muscle damage and overtraining in male and female WLFF.

Null Hypotheses

Main Measures

1. Activities performed during a two-week critical training period in WLFFs will result in no change in body weight or composition.
2. Activities performed during a two-week critical training period will result in no differences in serological markers of muscle damage, creatine kinase and lactate dehydrogenase, throughout the four time points of blood collection.
3. There will be no difference in markers of inflammation, C-reactive protein, throughout the four time points of blood collection.
4. There will be no difference in blood cortisol, testosterone, or the corresponding testosterone/cortisol ratio from baseline values over the four blood collection data points of CT.
5. There will be no difference in perceptive ratings of daily muscle soreness during CT as compared to baseline.

Secondary Measures

1. There will be no correlative relationship between markers of individual fitness and biologic markers of muscle damage, muscle soreness, or overtraining.
2. There will be no correlative relationship between pre-season training habits and biologic markers of muscle damage, soreness, or overtraining.

Significance and Rationale

Sufficient physical and technical preparation is critical for WLFF to perform their fire-suppressing duties for the entire fire season. Currently, components of CT prepare these men and women for these tasks, as there is no standardized training regimen

during the off-season. However, due to the multitude of injuries that occur during this part of the season, a better understanding of the potential overtraining and muscle damage is needed. When there is muscle damage during CT, steps should be taken to alter the training to allow for better adaptations as opposed to debilitation. Improved education for WLFF on ways to improve off-season fitness to improve physical health at the start of the fire season is necessary. These findings would expand the research behind the physiological stresses that WLFFs undergo, hopefully enhancing the efficacy of WLFF crews and preventing incapacitating injuries.

Delimitations

1. Subjects were delimited to male and female WLFF, 18 years or older, in the Lolo International Hotshot Crew, permanent and seasonal, employed by the U.S. Forest Service.
2. Participants were asked to limit activity level and abstain from eating on mornings of blood collection.
3. The purpose of this study was to obtain baseline values to compare to potential alterations in biologic markers of interest.
4. Care was taken to train researchers and calibrate equipment to minimize possible effects of human error when using instrumentation.
5. This study focuses on serological and subjective markers of interest, focusing on the times of data collection.

Limitations

1. Subjects were a convenient sampling of a local Interagency Hotshot Crew.
2. Participants' diets and behaviors were not controlled outside the testing period.

3. Prior to their involvement with the study, approximately seven crew members had already completed at least one controlled burn, challenging true baseline values.
4. There are inherent limitations to accuracy and specificity of values obtained using instrumentation.
5. Activity data throughout the training period is outside the scope of this study. WLFF have different daily assignments during CT, so all crew members did not have equal levels of physical exertion or smoke exposure.

Assumptions

1. It is assumed that the Lolo IHC is a representative sample of the WLFF population as a whole.
2. It is assumed that any non-training associated activity or diet is within normal daily function of these WLFFs.
3. It is assumed that baseline values made a valuable contribution to the literature.
4. It is assumed that adequate training and monitoring will result in valuable and sufficient data for analysis.
5. It is assumed that the specific daily tasks are representative of the average WLFF expenditure, particularly in field research settings.

Definition of Terms

BLM Fitness Challenge: This voluntary testing protocol, as determined by the Bureau of Land Management (BLM), utilizes four basic exercises (a timed 1.5-mile run, push-ups, pull-ups, and sit-ups) to assess the relative fitness of WLFFs. Individual results for each event are scored and combined using an established score sheet and used to compare performance and readiness across WLFF crews.

Critical Training (CT): Critical training is a period of time, usually two weeks, where IHCs undergo various physical challenges and job training to verify preparedness for the fire season ahead. This training includes physical tasks as well as logistical and safety procedures. CT must be completed before the IHC's become available for incident assignment ¹².

Delayed Onset Muscle Soreness (DOMS): The classification of muscle soreness where the onset is 24 hours after exercise completion, with symptoms peaking around 72 hours and usually resolving within seven days ²⁴.

Interagency Hot Shot Crew (IHC): Type I classification for a crew consisting of 20-22 WLFFs that have undergone additional training and certifications to be considered an elite subset of WLFF ¹².

Rhabdomyolysis: Rhabdomyolysis is a clinical syndrome resulting from skeletal muscular injury when intracellular contents are released into the plasma ²⁵. Rhabdomyolysis can result in myoglobinuria and other acute kidney injuries, potentially leading to renal failure ¹⁹.

Wildland Firefighter (WLFF): A wildland firefighter is any individual employed or contracted by the U.S. Forest Service, National Park Service, Bureau of Land Management, Bureau of Indian Affairs, and U.S. Fish and Wildlife Service and volunteers. Occupational tasks include wildfire management activities such as preventing, battling, or cleaning up wildland fires using specific tools and techniques ¹¹.

CHAPTER TWO: REVIEW OF LITERATURE

Exercise and Muscle Damage

Exercise-induced muscle damage (EIMD) commonly occurs during strenuous, unaccustomed exercise, such as the initiation of a training stimulus like CT¹⁴. EIMD is characterized by the loss of muscle force, swelling, transient myofibrillar disruption, reduced range of motion, and efflux of myocellular proteins²⁶. Indirect measures of EIMD are quantifiable, but the loss of muscle force is the most direct indication²⁷. These disruptions are best established in eccentric and isometric contractions²⁸⁻³⁰.

The proposed mechanism behind this damage involves both direct damage and subsequent cellular actions that magnify the effect. First, mechanical strain during eccentric exercise causes over-stretching of sarcomeres, resulting in disrupted sarcomeres. This directly reduces force production and overloads the t-tubules and sarcolemma. These events then cause an opening of stretch-activated channels, membrane disruption, and excitation-contraction coupling malfunction. With these interruptions, Ca²⁺ enters the cytosol and/or the “leaky” sarcolemma stimulates calpain enzymes to degrade contractile proteins, resulting in a prolonged loss of muscle strength²⁶. Literature suggests this sarcomeric disturbance peaks between 24- and 72-hours post-exercise and can remain elevated for up to eight days^{31,32}. The degree of force production loss is directly associated to time required to restore muscle strength and directly impacts the severity of corresponding physiological modifications^{31,33,34}.

Chronically, EIMD can decrease insulin sensitivity, inhibit glycogen synthesis, and alter the metabolic profile, while the most direct response is acute inflammation³⁵. Previous research has established localized leukocyte presence in muscle tissue within

24 hours of intense, long-duration, and unaccustomed exercise, which continues to accumulate within the extracellular space 24-48 hours post-exercise^{31,36,37}. While inflammation was once considered a detrimental process, it is now accepted as a critical process in muscular repair, when in moderation³⁸⁻⁴⁰.

Despite these concerns, skeletal muscle has the ability to adapt following exercise, and muscle damage has been shown to attenuate following a second session of exercise⁴¹. Known as the repeated bout effect (RBE), this phenomenon most likely results from adaptations to the inflammatory response and the excitation-contraction coupling pathway, and is demonstrated after one or two days and can remain for months after the initial bout^{42, 43}. Overall, EIMD can occur in a wide variety of physical activities and has short- and long-term consequences that affect performance and safety during field operations.

Muscle Soreness

Muscle soreness caused by EIMD presents as muscle stiffness, aching, and tenderness with corresponding muscle weakness^{15,44,45}. This soreness can manifest acutely as a grade one muscle strain that presents with pain, during or immediately after exercise, and resolves within a few hours, or as delayed onset muscle soreness (DOMS)^{24,46}. DOMS is a classification of muscle soreness where the onset is 24 hours after exercise completion, with symptoms peaking around 72 hours and usually resolving within seven days²⁴. Enumerating muscle soreness can be done indirectly by examining biomarkers of EIMD, or more directly using standardized pain scores. Utilizing a 10 cm continuous visual analog scale that ranges from zero pain to maximum

pain, researchers are able to translate a subjective marker with high individual variability into a quantifiable metric.

Currently, evidence suggests that DOMS results from muscle fiber damage and subsequent inflammation ⁴⁷. The responsible mechanism is heavily debated, but there are two current promising theories. In 2010, Murase et al. demonstrated that bradykinin, released during exercise, uses B2 receptors to upregulate nerve growth factor, which plays an essential role in creating mechanical hyperalgesia ⁴⁸. A 2013 follow-up study found that COX-2, produced during inflammation, upregulates a glial cell line-derived neurotrophic factor, which elicits similar delayed soreness results ⁴⁹. Currently, researchers estimate that the actual mechanism is most likely a combination of these two pathways.

DOMS can occur after a variety of exercise protocols. Paddon-Jones et al. examined muscle soreness after 36 maximal, isokinetic eccentric contractions using elbow flexors of the non-dominant arm ⁵⁰. Using a 12-point soreness rating scale, upper limb muscle soreness began to significantly increase 45 minutes after completing the bout of exercise, peaking 48 hours later at 5. Interestingly, after completing the second round of flexor exercises at the 48-hour mark, there was no significant additional increase in muscle soreness. Elevated soreness continued for subsequent days, with values returning to baseline after seven days. During the Western States 100 (a 160 km ultramarathon), 60 male and female runners were asked about their soreness levels for the seven days post-race ⁵¹. On a 10-point pain scale, the average participant score was ~3.5 directly post-race. These values increased to 7.1 ± 0.3 24 hours post-race.

Beyond that time point, the pain scale values attenuated over the subsequent days, to 1.6 ± 0.1 , or close to no soreness on Day 7.

DOMS is an excellent subjective indicator of EIMD, though the exact degree of damage cannot indiscernibly be determined based on pain. Importantly, muscle pain can hamper performance, impeding an individual's ability to succeed at designated tasks. This is crucial for WLFFs, as they are tasked with multiple physically demanding duties daily. Therefore, it is essential to include DOMS in evaluations of EIMD and quantification of this marker should be utilized as a diagnostic tool to form guidelines and recommendations.

Exertional Rhabdomyolysis

When EIMD exceeds physiologically manageable levels, exertional rhabdomyolysis (ER) can occur. Symptoms include pain, swelling, dark urine, rapid heart rate, and vomiting ^{15,20}. Clinically, diagnosis is based on a combination of CK, Mb, potassium, creatinine, and phosphorus levels in the plasma ²⁵. Once diagnosed, short-term treatment goals include preventing renal failure, heart arrhythmias, and death, while continual monitoring is necessary to determine an adequate timeline for re-entry to regular physical activity ^{19,52}. Secondary factors such as hypoxic situations, high temperatures, dehydration, genetic conditions such as sickle-cell trait, lower training status, drugs, and ergogenic aids can exacerbate the response ^{15,53}.

ER occurs in a wide variety of physical activities, in both trained and untrained individuals. In untrained individuals, the beginning of an exercise program can elicit ER. In 2017, a 15-year-old girl presented with bilateral swelling of the upper limbs after performing 50 push-ups for the first time in her life; she was diagnosed with ER after CK

levels were found to be elevated to 6626 U·L⁻¹ ⁵⁴. Unaccustomed activity in combination with intrinsic and extrinsic factors motivating one to exert beyond a point of fatigue where most would self-limit can result in higher risks of ER. This is common in team settings, such as high school and college athletes, military settings, and in WLFF crews. In 2018, 12 of 43 high school football teammates were hospitalized with ER after completing a football camp consisting of intense eccentric-focused drills ⁵⁵. Even highly trained individuals can experience ER, as adequate training loads cannot account for excessive eccentric movements. In 2015, six cases of rhabdomyolysis occurred in 113 ultra-runners and ultra-mountain bikers, with CK values ranging from 14,000 - 29,702 U·L⁻¹ ⁵⁶.

In the wildland fire community, 26 confirmed cases of rhabdomyolysis occurred from 2008-2016, though there are most likely many more that went unreported. Seventeen of these cases occurred during early season physical training (PT), with six occurring during PT running, two during hiking, six during other PT, and three during work capacity testing ²². The 2016 season alone presented four cases of rhabdomyolysis in the first four days of training, three of these cases on the first day. The military experiences high rates of rhabdomyolysis as well. Three separate case studies explain the ER present in young, male individuals after undergoing crawling training, without any other extreme exercise ⁵⁷. Similarly, another case study details another young male that underwent vigorous squatting exercises and required hospitalization 48 hours after the exercise due to extreme pain in lower extremities ⁵⁸. Laboratory results indicated elevated CK and extreme myoglobinuria, confirming ER. New recruits are more susceptible to this type of injury, as they are not yet accustomed

to the rigorous physical activity. In 2018 alone, there were 545 incidents of rhabdomyolysis in the military, with recruit incidences 6x more than other enlisted members and officers ²¹. Due to the nature of the professions, rhabdomyolysis may continue to occur in WLFFs and other arduous occupations, but better education and preparation are necessary to prevent ER best.

Together, the current state of “scientific consensus” based on existing peer-reviewed literature suggests that a multitude of exercise intensities and durations can result in EIMD sufficient to elicit rhabdomyolysis, even despite training status. Occupations involving arduous physical activity, such as WLFF, are of further concern due to elevated secondary risk factors such as high temperatures and dehydration. It is necessary to investigate the markers of muscle damage and overtraining in WLFFs during CT in order to better comprehend the risks and avoid potential injuries in the future.

Indirect Markers of Muscle Damage

Analyzing EIMD can be problematic, as there is not currently a “gold-standard” marker of muscle damage. Multiple methodologies are utilized, including isolating muscle tissue to complete immuno-histological staining for examination of cellular protein complexes and electron micrograph imaging for Z-line streaming of the skeletal muscle ¹⁴. However, these options require invasive techniques to biopsy the muscle tissue. To avoid these procedures, a biomarker panel is utilized to examine indirect plasma markers of muscle damage and associated secondary inflammation ⁵⁹.

Creatine Kinase

Creatine kinase (CK) is an intracellular enzyme responsible for both the regeneration of phosphocreatine from mitochondrially produced ATP and phosphorylation of ADP. When there is an amplified need to restore phosphocreatine for ATP synthesis, such as strenuous exercise, CK activity is allosterically elevated within skeletal muscle. However, when the body's physical capacity is overreached due to trauma, pathology, or vigorous exercise, muscle damage can occur and intracellular components are released into the systemic circulation, including CK⁶⁰. Therefore, CK is used diagnostically as an indirect marker of muscle damage.

Across the body of existing literature, CK has not been widely assessed in WLFF, though one study examined CK in structural firefighters. When comparing Jeddah and Yanbu firefighters, two subsets of Saudi Arabian firefighters, immediately post-shift to a non-firefighter male control group, firefighters exhibited elevated CK up to $183.5 \pm 93.7 \text{ U}\cdot\text{L}^{-1}$, compared to $112.9 \pm 33.5 \text{ U}\cdot\text{L}^{-1}$ in the control group⁶¹. However, this data is limited as the exercise status of the control group was not established. While data is limited in firefighters, it has been studied extensively in other exercise situations.

Baseline CK levels in unstressed individuals range between $35\text{-}175 \text{ U}\cdot\text{L}^{-1}$ and increase with physical activity, though the magnitude is dependent on the type, intensity, and duration of the exercise procedure⁶². Females typically having lower resting CK values than males, and these differences remain relevant post-exercise^{63,64}. During resistance exercise, circulating CK increases dependent on the protocol. In a study comparing three sets of 4 and three sets of 8 repetitions for 80% of their one-rep max load in the bench press and squats, there were slight differences in circulating CK

levels between the two protocols. In the three sets of 4 repetitions group, there was no significant increase in CK from the pre-exercise values of $156.8 \pm 86.5 \text{ U}\cdot\text{L}^{-1}$. However, 48 hours post-exercise, CK increased to $348.0 \pm 177.6 \text{ U}\cdot\text{L}^{-1}$. In the three sets of 8 repetitions group, there was an immediate significant CK increase from $139.6 \pm 84.2 \text{ U}\cdot\text{L}^{-1}$ to $260.0 \pm 134.0 \text{ U}\cdot\text{L}^{-1}$, and values remained elevated 48 hours afterwards⁶⁵. In 2010, Magal et al. investigated 17 untrained college-aged males, inducing a muscle-damaging protocol on the left leg, consisting of completing 50 eccentric actions with three-minute rest periods between sets. Compared to pre-exercise values of $146.2 \pm 32.2 \text{ U}\cdot\text{L}^{-1}$, CK elevated significantly 24 hours post-exercise to $314.5 \pm 47.5 \text{ U}\cdot\text{L}^{-1}$, with a gradual decrease towards baseline values at 48 hours¹⁶. The timeline to CK peak within the blood is dependent upon the strength of the stimulus and subject to individual variability and muscle fiber type.

Aerobic exercise increases circulating CK more than resistance exercise. During a standard distance triathlon (1.5 km swimming, 40 km cycling, and 10 km running), CK increased significantly from baseline values of $168.0 \pm 37.4 \text{ U}\cdot\text{L}^{-1}$ to $466.5 \pm 181.6 \text{ U}\cdot\text{L}^{-1}$ immediately post-race. Three hours after the race, those values had returned to baseline values⁶⁶. In the same study, the ultra-distance triathlon (1.9 km swimming, 90 km cycling, and 21 km running) exhibited augmented circulating CK up to $1,128.0 \pm 247.6 \text{ U}\cdot\text{L}^{-1}$ immediately post-exercise, with similar recovery shown three hours afterward. During the 2001 Boston Marathon, 37 participants were studied pre-, directly post-, and 24 hours post-marathon. Compared to pre-race values, total CK levels increase from $131.9 \pm 57.8 \text{ U}\cdot\text{L}^{-1}$ to $843.8 \pm 782.3 \text{ U}\cdot\text{L}^{-1}$. These values continued to rise, peaking at $2,470.0 \pm 1,950.0 \text{ U}\cdot\text{L}^{-1}$ 24 hours post-race⁶⁷. During the Western States 100

Endurance Run, a 160 km ultramarathon, plasma CK levels in 36 ultramarathoners increased from $171.0 \pm 27.0 \text{ U}\cdot\text{L}^{-1}$ pre-race to $19,626.0 \pm 3,981.0 \text{ U}\cdot\text{L}^{-1}$ directly post-race⁶⁸.

Within the blood plasma, CK increases are clearly caused by eccentric muscular movement as opposed to concentric movement. In a 1992 study, two female groups completed isokinetic exercise consisting of three sets of 35 repetitions of $120^\circ/\text{sec}$ knee flexion or extension at 80% of their peak torque⁶⁹. Post-exercise, there were significant increases in CK values 48 and 72 hours in the eccentric group, with peak values reaching $14,846.0 \text{ U}\cdot\text{L}^{-1}$. In contrast, the concentric group remained at baseline, with CK values at $360.0 \text{ U}\cdot\text{L}^{-1}$ 72 hours after completion of the protocol. In 2016, Castellani et al. examined five males and three females, conducting an eccentric exercise of the arms on a modified preacher curl bench with the bar attached to complete two bouts of 24 maximal eccentric actions⁷⁰. CK levels increased 72 hours post-exercise to 3200–4325% of their pre-exercise values and remained elevated 120 hours after protocol completion.

Exercise can stimulate CK level changes, with degrees of change dependent on the stimulus. While some increases are mild, extreme exercise can stimulate radical changes. Clinically, when diagnosing extreme muscle damage, such as rhabdomyolysis, physicians look for CK values $>500 \text{ U}\cdot\text{L}^{-1}$ in combination with other markers. Levels $>5,000 \text{ U}\cdot\text{L}^{-1}$ indicate an increased risk of an acute kidney injury¹⁹. As a vital indirect marker of muscle damage, CK is necessary for determining the degree of muscular trauma in WLFFs.

Myoglobin

Unique to cardiac myocytes and oxidative skeletal muscle fibers, myoglobin (Mb) is a cytoplasmic hemoprotein well known for its limited but physiologically important role in O₂ storage⁷¹. Similar in structure and role as hemoglobin, Mb acts as a local muscular oxygen reservoir, temporarily providing oxygen during periods of intense muscular activity⁷². Acutely, Mb is used as a biomarker of muscle injury in parallel with CK, as it is rapidly released after muscular damage and quickly cleared from the system^{19,73}. Myoglobinuria occurs when Mb is excreted in the urine (causing dark coloration) and when there is extreme muscle damage, acting as a common symptom of rhabdomyolysis²⁵. However, Mb has a short half-life in circulation and serum levels may return to normal in 3-6 hours, while CK is still rising⁷⁴. There is no evidence of Mb data in firefighters, but Mb has been studied in a variety of other exercise scenarios.

During a full distance Ironman triathlon, Mb markers were evaluated pre-race, directly post-race, and one-week post-race in 29 individuals (n=15 males, n=14 females)⁷⁵. Immediately post-race, Mb levels increased drastically in all participants compared to $44.4 \pm 29.7 \mu\text{g}\cdot\text{L}^{-1}$ mean baseline value, though males saw a much more significant increase ($\sim 2,400 \mu\text{g}\cdot\text{L}^{-1}$) compared to females ($\sim 1,100 \mu\text{g}\cdot\text{L}^{-1}$). One week after race completion, both males and females had Mb values return to baseline. Similar results were found in a comparable study investigating a half Ironman Triathlon, with Mb increasing from $14.0 \pm 17.0 \mu\text{g}\cdot\text{L}^{-1}$ pre-race to $516.0 \pm 248.0 \mu\text{g}\cdot\text{L}^{-1}$ immediately post-race⁷⁶.

However, extreme exercise is not necessary to produce changes. Mb has been investigated during plyometric exercises when 26 untrained, healthy, male subjects

performed ten sets of 10 maximal squat jumps, with a one-minute recovery between sets ⁷⁷. Six hours post exercise, Mb significantly elevated to $\sim 250 \text{ ng}\cdot\text{mL}^{-1}$ from the $\sim 25 \text{ ng/ml}$ baseline. After separating participants into CK responders (values exceeding $1,000 \text{ U}\cdot\text{L}^{-1}$) and non-responders, Mb remained elevated four days post-exercise, peaking day three at $\sim 700 \text{ ng}\cdot\text{mL}^{-1}$ in the responder group, while non-responders exhibited Mb returning to baseline values beyond the six-hour mark. During a high-intensity interval resistance training (HIIRT) protocol, 54 subjects completed eight sets of Tabata style squats at the highest speed possible for 20 seconds, with 10 second rest periods between sets ⁷⁸. Two hours post-exercise, Mb values significantly increased from $21.0 \text{ ng}\cdot\text{mL}^{-1}$ to $88.6 \text{ ng}\cdot\text{mL}^{-1}$ and remained elevated 24 hours post-HIIRT.

Changes in Mb occur post-physiological stress: the magnitude variable is dependent on the stimulus. Directly after an event, Mb is useful tool, identifying muscle damage in line with CK. Immediate samples are required in order to detect elevated levels due to the short half-life of the protein. However, to observe alterations in Mb during WLFF work, sample acquisition directly post-shift would be necessary.

Lactate Dehydrogenase

Lactate dehydrogenase (LDH) catalyzes the interconversion of pyruvate and lactate with the completion of glycolysis when glucose is metabolized to produce ATP for energy with concurrent interconversion between NADH and NAD. This anaerobic pathway is common in times of rest to exercise transitions or when the aerobic capacity of ATP production is insufficient to match ATP demand. Similar to CK, LDH is used as

an indirect marker of muscle tissue damage as it is unable to cross the sarcoplasmic membrane barrier by itself ²⁸.

Baseline plasma LDH levels range between 140-280 U·L⁻¹ but can increase depending on the duration and intensity of activity stimulating muscle damage ⁷⁹. Prior to starting a resistance training program following a Delorme or Oxford method, 32 healthy men underwent a resistance exercise test ⁸⁰. Directly post-exercise, LDH levels increased from ~200 U/L to ~400 U·L⁻¹ and continued to increase up to 72 hours post-exercise where they peaked at ~600 U·L⁻¹ (with no significant difference between the groups). After the 23-day resistance training protocol, the test was repeated, and LDH values were decreased compared to the pre-values, though values elevated similarly over the 72 hours, peaking at ~450 U·L⁻¹.

Directly post-marathon in recreational runners, LDH increased almost twice the baseline values of 323.0 U/L, remaining elevated until eight days after the race consistent with values seen during the 2002 London Marathon, with LDH values in 34 participants (27 male, 7 female) increasing from 429.2±64.5 U·L⁻¹ pre-race to 824.5±220.9 U·L⁻¹ post-race^{79,82}. Extending to the Leadville 100 Ultramarathon, a distance of 160 km, LDH values averaged 663±406 U·L⁻¹, ranging up to 2324 U·L⁻¹, with 82% of the 112 runners sampled presenting abnormal values immediately post-race ⁵⁹.

LDH has not been examined in WLFFs, although it has been briefly studied in structural firefighters. In a 1974 study examining the Oklahoma City Fire Department, 36 male firefighters exhibited significantly augmented baseline LDH levels when compared to closely-matched individuals from local military reserve units ⁸¹. These increases were associated with the occupational demand of firefighters, specifically the

smoke exposure component of the position. Similarly, when comparing Jeddah (n=28) and Yanbu (n=21) firefighters to a non-firefighter male control group (n=23), firefighters exhibited increased LDH levels, $241.8 \pm 124.4 \text{ U} \cdot \text{L}^{-1}$ and $164.2 \pm 28.2 \text{ U} \cdot \text{L}^{-1}$, to $143.2 \pm 21.6 \text{ U} \cdot \text{L}^{-1}$ respectively ⁶¹. Samples were taken within an hour after firefighting, though there was no specification of type, scale, or duration of fire, and there was no clarification on if the control group had exercised or was sedentary pre-blood draw. Overall, plasma LDH can increase in both resistance and aerobic exercise in a dose-dependent manner. This is significant as plasma LDH indicates myocyte damage which can impede function of the muscle. There is limited documentation of LDH responses in firefighters, and further evaluation must be completed in order to determine potential LDH increases during CT.

Inflammation and C-Reactive Protein

Exercise that induces EIMD results in the increase in intracellular calcium concentrations, elevated calpain activity, and the induction of an inflammatory response ⁸². This inflammation is mediated by a combination of pro- and anti-inflammatory markers that respond to local tissue injury, producing cytokines that mount an appropriate immune response to heal tissue and clear any present pathogens. This balance has been shown to be crucial for tissue repair that can occur during EIMD.

C-reactive protein

Synthesized mainly by hepatocytes, C-reactive protein (CRP) is an acute-phase protein found in blood plasma ⁸³. Trace levels are always found in serum, but levels rise drastically and rapidly in response to tissue inflammation, stimulated by cytokines such

as interleukin-6, interleukin-1, and tumor necrosis factor ⁸⁴. After stimulation, the protein activates a complement cascade to induce a pro-inflammatory response, triggering a humoral, adaptive immune response ⁸⁵.

CRP elevation can be stimulated by pathologic conditions such as appendicitis, pneumonia, and other infections, but can also be elevated in certain exercise situations ^{69,86}. After intense, unaccustomed, muscle damage-inducing exercise, CRP has been investigated as a biomarker of secondary damage ⁷⁷. In healthy individuals at rest, values are typically below 10 mg·L⁻¹, but depending on the inflammatory stressor, measures can rise to 350-450 mg·L⁻¹ and peak after approximately 48 hours ⁸⁶.

CRP has not been examined during CT in WLFF, though there is limited data in firefighters exposed to heat. In 2015, Watt et al. investigated CRP levels in fire instructors exposed to high temperatures compared to a neutral temperature control group. There were no significant differences between the instructors in the control group after the two heat exposure sessions, though instructors did have elevated baseline values, indicating potential ongoing inflammatory issues ⁸⁷. However, these fire instructors were not engaging in the intense physical activity of other firefighters, so results may not translate effectively.

Increased intensity and duration associate with elevated CRP values in a dose-dependent manner. In a study examining plyometric exercises in 26 untrained, healthy males (10 sets of 10 maximal squat jumps, with a one-minute recovery between sets), when CK >1,000 U·L⁻¹, CRP values elevated from ~4 mg·mL⁻¹, peaking 24 hours post-exercise at ~18 mg·mL⁻¹, though they remained elevated four days post-protocol ⁷⁷. However, an examination of isokinetic exercise in healthy individuals (three sets of 35

repetitions of 120°/sec knee flexion or extension) showed no significant elevations in CRP post-exercise, indicating there is a baseline intensity threshold to elicit an inflammatory response ⁶⁹.

CRP has also been examined in more exhaustive exercise bouts. In the Western States 100 km endurance run, 39 male and female runners exhibited a significant increase in CRP post-race, from $0.8 \pm 0.2 \text{ mg} \cdot \text{L}^{-1}$ to $39.0 \pm 5.1 \text{ mg} \cdot \text{L}^{-1}$ ⁶⁸. During a three-day multistage Ultraman triathlon (stage 1 = 10 km swim, 144.8 km bike; stage 2 = 275.4 km bike; stage 3 = 84.4 km run), CRP increased from $366.9 \pm 661.4 \text{ ng} \cdot \text{mL}^{-1}$ at baseline to $9322.0 \pm 11,213.8 \text{ ng} \cdot \text{mL}^{-1}$ post-race ⁸⁸. Though there is an astounding increase, it is important to note the large individual variability amongst the participants. Though CRP can elevate across multiple modes and intensities of exercise, the degree of change, if any, is dose-dependent, and needs to be evaluated in WLFF to determine the degree of secondary damage associated with CT.

Overtraining

An imbalance between the strain experienced during exercise training and tolerance to that effort can induce overreaching or overtraining syndrome. This syndrome is characterized by diminished physical performance, enhanced fatigue, and subjective symptoms of stress ⁸⁹. The imbalance between training and recovery can be worsened by inadequate nutrition, psychological stressors, and sleep disturbances; this can lead to dysfunction of the inflammatory and hormonal systems. While there are no set parameters to measure overtraining, cortisol and testosterone are often used to determine the catabolic/anabolic ratio, which can provide useful information in the evaluation of acute and chronic effects of training ⁹⁰.

Cortisol

Cortisol is a critical catabolic hormone involved in the stress response. When exposed to a stressor, the limbic system of the body stimulates the amygdala in the brain to release a sympathetic response, quickly followed by a neuroendocrine response to attempt to restore the body to homeostasis^{91,92}. This second response includes the release of cortisol from the adrenal cortex of the kidneys which works to combat the sympathetic response, maintaining blood glucose and suppressing non-essential organs⁹³. Additionally, cortisol is a vital anti-inflammatory hormone that alters leukocyte function and inhibits pro-inflammatory cytokines^{92,94}. Due to this interaction, cortisol can affect the recovery process after a muscle-damaging bout of exercise⁹⁵.

Cortisol is secreted following exercise in a dose-dependent manner. Secretion is dependent upon the workload, fitness level, duration, and type of exercise⁹⁶. The pulsatile nature and diurnal rhythm of cortisol can affect secretion values, with baseline quantities peaking half an hour after waking, then continuously dropping throughout the day⁹⁷⁻⁹⁹. Cortisol typically returns to baseline values 2-4 hours after a competition or bout of exercise, with similar responses despite the time of day^{99,100}. However, due to its diurnal controls, cortisol can be a problematic biomarker when not adjusted for time of day or involving a time-dependent intervention, as consistent sampling is crucial for adequate comparative values.

Little investigation has been done on chronic cortisol concentrations in WLFF, though a 2018 study did survey the two-week Navy Survival, Evasion, Resistance, and Escape (SERE) training course. During this investigation, participants were assessed on three separate days; day 1 of training for baseline measurements (T1), 10 days into

training following multiple days of physical, psychological, and environmental stressors (T2), and one day after the training to assess recovery (T3). All blood samples were collected at the same time of day with participants fasted ¹⁰¹. During T2, serum cortisol increased to $766.9 \pm 157.9 \text{ nmol} \cdot \text{L}^{-1}$, increasing 5x from the baseline. During T3, values significantly decreased to $333.8 \pm 128.3 \text{ nmol} \cdot \text{L}^{-1}$, though they remained elevated from baseline values.

Prolonged endurance exercise triggers significant increases in cortisol values. Twelve endurance-trained athletes underwent a prolonged exercise bout (>75 min) until volitional fatigue ¹⁰². Directly post-exercise, cortisol values increased to $700.8 \pm 177.7 \text{ nmol} \cdot \text{L}^{-1}$ from the baseline $331.8 \pm 42.9 \text{ nmol} \cdot \text{L}^{-1}$. Values then began to decrease, dipping below baseline values 24 hours post-exercise to $209.3 \pm 67.1 \text{ nmol} \cdot \text{L}^{-1}$, then returning to normal values in 24 hours. During an extended, three-day, multistage Ultraman triathlon, the athletes' cortisol elevated post-race to $207.9 \pm 108.9 \text{ ng/mL}$ from pre-race values of $60.2 \pm 32.5 \text{ ng} \cdot \text{mL}^{-1}$ ⁸⁸. Though a substantial increase was shown, there is no mention of cortisol release timing, indicating potential interference from circadian patterns. Similar increases were seen directly after the Western States 100 ultramarathon, where participants' cortisol rose to $806 \pm 97 \text{ nmol/L}$, almost doubling baseline values ⁶⁸.

Any stressor, physiological, environmental, or psychological, can stimulate the production of cortisol. WLFFs are exposed to all three of these stressors daily, especially during CT. Examining cortisol levels can help determine the degree of stress WLFFs undergo and examine anti-inflammatory properties cortisol provides.

Testosterone/Cortisol Ratio

Testosterone is a key anabolic hormone with multiple physiological functions. Secreted from the testes in males and the adrenal glands and ovaries in females, testosterone is vital to the growth and maintenance of skeletal muscle, bone, and red blood cells ⁹⁵. Testosterone concentrations increase linearly during aerobic exercise, but have been shown to decrease following exhaustive bouts ^{95,102}. Szivak et al. examined the effect of an eleven-day navy SERE training on testosterone, and found that in males, testosterone significantly decreased following ten days of physical and psychological stress ($14.8 \pm 4.7 \text{ nmol}\cdot\text{L}^{-1}$ to $5.5 \pm 4.1 \text{ nmol}\cdot\text{L}^{-1}$) and these values remained attenuated after a 24-hour recovery period ¹⁰¹.

The interaction of cortisol and testosterone is studied as an indicator of the catabolic or anabolic state of the body, and therefore the recovery capacity of the body after strenuous exercise, as they are highly involved with protein breakdown and synthesis ^{95,103}. Elevated cortisol concentrations due to physiological stress correspond with depression of circulating testosterone during exercise recovery, which can impede skeletal muscle repair and inhibit muscle growth ¹⁰⁴. The testosterone/cortisol ratio describes this anabolic/catabolic balance and the physiological strain of training. Current research suggests that a significant decrease in this ratio (>30%) indicates poor exercise recovery and a maladaptation of the hypothalamic-pituitary-adrenal axis ¹⁰⁵. Attenuated recovery can result in muscular compensatory mechanisms, adding strain to tendons and ligaments, therefore increasing the risk of injury ⁹⁰. Testosterone concentrations are naturally lower in females, confounding any evident training responses, but utilizing the ratio offers a standardized tool to determine the

anabolic/catabolic balance within both sexes. In the Navy SERE training study, the testosterone/cortisol ratio decreased from 0.117 to 0.007 (nmol/L) in males after ten days of stress (94.1%) and from 0.007 to 0.001 (nmol/L) in females (84.8%). This ratio rebounded after a 24-hour recovery period to 0.020 in males and 0.003 in females. Ultimately, testosterone and the testosterone/cortisol ratio can be a strong indication of whether the physiological demands of CT are manageable to the WLFF and the level of recovery that can occur throughout the training.

Summary

EIMD can occur after unaccustomed, strenuous exercise, such as the initiation of CT after an off season. EIMD is quantifiable using indirect biomarkers (CK, Mb, LDH, CRP) that are responsive to both acute and chronic exercise training. This damage can cause muscle soreness, which can affect performance and safety during subsequent exercise bouts. If the EIMD exceeds the body's capacity, ER can occur, which can have innumerable clinical consequences. Rhabdomyolysis is of concern to the WLFF, as 26 cases were reported between 2008-2016, with 17 of those occurring during early season PT. Preparation for the intense occupational demands is necessary, but intense training can result in overtraining, determined by the balance between the catabolic and anabolic pathways within the body (cortisol and testosterone). It is necessary to balance that ratio to allow beneficial adaptations without impeding exercise recovery to prevent injury. Ultimately, while these responses have been established in numerous exercise situations, there has been no investigation of these markers during WLFF CT. This is necessary to provide adequate training and education to WLFF to best impact performance and safety during field operations.

CHAPTER THREE: METHODOLOGY

Subjects – Twenty-one healthy adults (18 males, 3 females) were recruited from a local IHC crew for participation in this study. Each subject was required to complete a participation readiness questionnaire (PAR-Q) to exclude those with contraindicated health conditions. Moreover, subjects were allowed to withdraw from participation at any time (Appendix A). Inclusion criteria included being 18 years or older and a member of an IHC WLFF crew partaking in CT. Before data collection, all subjects read and signed an informed consent form approved by the University of Montana Institutional Review Board (#50-19).

Experimental Design – Participants were followed during an 11-day critical training period. On the first Monday of the training period, participants completed paperwork including informed consent, PAR-Q, preparedness questionnaire, and an initial muscle soreness scale which was repeated each day. Body weight was measured to the nearest tenth of a kilogram each morning of training (Salter Brecknell, Fairmont, Minnesota). Two training hikes were completed on Day 1 (with 45 lb backpacks) and Day 10 (with 45 lb backpacks and chainsaws). Body composition was measured on Day 1 and Day 11. Four antecubital blood draws were taken during the two weeks on Days 1, 4, 8, and 11, with subjects fasted and uncaffeinated (Figure 1). A BLM fitness challenge was completed to determine individual fitness.

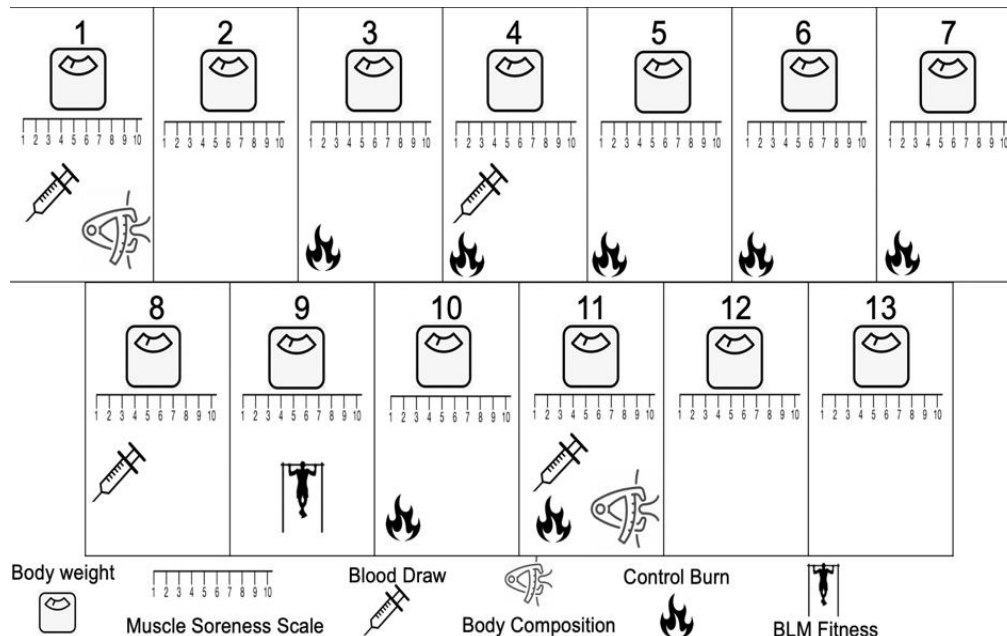


Figure 1. Main experimental design

Body Composition – Body weight measurements were obtained each morning, to the nearest tenth of a kilogram (Salter Brecknell, Fairmont, Minnesota). Shorts and t-shirt were the only permitted clothing and were repeated each collection. Body weight and height were used to calculate body mass index (BMI). Body composition was collected using a three-site skin fold method using calibrated Lange skinfold calipers (Beta Technology, Santa Cruz, CA). Skin folds were taken in a rotational order measuring chest, abdomen, and thigh for men; tricep, supraillium, and thigh measurements were taken for women ^{106,107}. Measurements were repeated until results were within 2 mm. Body density was then calculated using established gender-specific formulas ^{106,107} and converted to body fat percentages using the Siri equations ¹⁰⁸.

Male:

$$Db = 1.10938 - (0.0008267 \times \sum 3) + (0.0000016 \times \sum 32) - (0.0002574 \times \text{age})$$

(Sum of 3 skinfolds (mm) = chest + abdomen + thigh)

$$\% \text{ body fat} = (495 \div Db) - 450$$

Female:

$$Db = 1.0994921 - (0.0009929 \times \sum 3) + (0.0000023 \times \sum 32) - (0.0001392 \times \text{age})$$

(Sum of 3 skinfolds (mm) = triceps + supraillium + thigh)

$$\% \text{ body fat} = (501 \div Db) - 457$$

Preparedness Questionnaire - Upon arrival on Day 1, participants completed a questionnaire regarding their physical preparedness for the upcoming exercise, detailing their offseason activity and training history (Appendix B).

BLM Fitness Challenge - A fitness assessment was completed to assess the relative fitness of WLFFs at the beginning of the season. In the assessment, participants complete a timed 1.5-mile run and have three minutes to perform as many repetitions of push-ups, pull-ups, and sit-ups as possible. Parameters may be performed in any desired order, with seven minutes of mandated rest observed between exercises (Appendix C). Individual results for each event are scored and combined using an established score sheet, with a maximum of 100 points possible per event (400 points available overall) (Appendix D). Individuals are ranked based on their total score per event (Level 1 – 100 points, ≥ 20 points/event; Level 2 – 100 points, ≥ 25 points/event;

Level 3 – 200 points, ≥ 25 points/event; Level 4 – 300 points, ≥ 25 points/event; Level 5 – 400 points).

Muscle Soreness Scale - Upon arrival every day, participants were asked to assess both upper and lower extremity soreness on a continuous 10 cm pain scale by marking a straight line from the top of the scale to the bottom at their appropriate pain levels (Figure 2). Marks were quantified using a ruler, in cm.

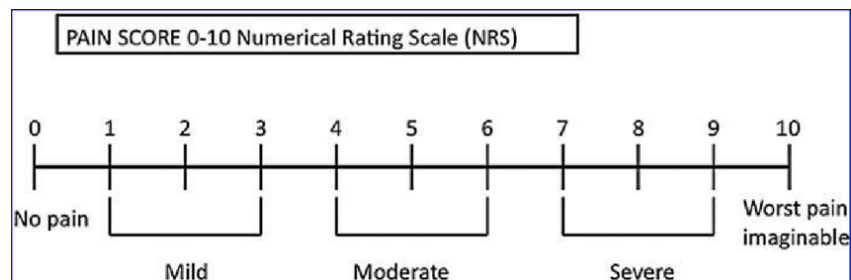


Figure 2. Pain scale distributed to participants to assess upper-limb and lower-limb soreness.

Blood Handling - Blood was collected using a sterilized antecubital venous draw technique in a 10 mL sodium heparin lined vacutainer (Becton, Dickinson and Company, Franklin Lakes, New Jersey). Whole blood was centrifuged in a vacutainer centrifuge (Ohaus Corporation, Parsippany, New Jersey) at 2,000 rpm for 10 minutes. Plasma was aliquoted into multiple 1.5 mL microcentrifuge tubes (Thermo-Scientific, San Diego, California). Plasma was stored at -80°C for later analysis.

Blood Analysis - Blood samples were collected to determine concentrations of creatine kinase (CK), lactate dehydrogenase (LDH), c-reactive protein (CRP), cortisol and testosterone on Days 1, 4, 8, and 11 using enzyme-linked immunosorbent assays (ELISA). Commercially available ELISA was used for CK (Bioassays Systems, Hayward, CA) according to manufacturer specifications, incubated at 37° C. Plasma was read by spectroscopy at 340 nm. Commercially available ELISA was used for LDH (Bioassays Systems, Hayward, CA) according to manufacturer specifications. Plasma was read by spectroscopy at 565 nm. Commercially available ELISA was used for CRP (Cayman Chemical, Ann Arbor, MI). Plasma was diluted to 1:200 using Assay buffer (5 µL plasma was added to 995µL assay buffer) based on standard procedures and read by spectroscopy at 450 nm. Commercially available ELISA was used for cortisol (Cayman Chemical, Ann Arbor, MI) according to manufacturer specifications, without recommended extraction. Plasma was diluted 1:100 using ELISA buffer (10 µL plasma was added to 990µL ELISA buffer) based on standard procedures and read by spectroscopy at 420 nm at 100 minutes. Commercially available ELISA was used for testosterone (Cayman Chemical, Ann Arbor, MI) according to manufacturer specifications, without recommended extraction. Plasma was diluted 1:100 using ELISA buffer (10 µL plasma was added to 990 µL ELISA buffer) based on standard procedures and read by spectroscopy at 420 nm at 70 minutes. Measures were performed in duplicate with inter-assay coefficient of variation under 10%.

Statistical Analysis - Body composition (BW, BMI, body fat %) was analyzed using a paired samples t-test. A one-way repeated-measures analysis of variance (ANOVA) were used to analyze CK, LDH, CRP, cortisol, testosterone, and muscle soreness. If a main effect of time was seen, a Bonferroni post-hoc analysis was completed. Two-tailed Pearson correlations were used to analyze all correlations. Statistical significance was set at a probability of type I errors less than 5% ($p < 0.05$). All data is represented as mean \pm SEM. All data analysis was conducted using SPSS data analysis software (SPSS Inc, Chicago, IL).

CHAPTER FOUR: RESULTS

Subject Descriptive Data

Twenty-one subjects (eighteen males, three females) participated in data collection. Descriptive data are presented in Table 1. Of the original subjects, seventeen subjects completed all days of muscle soreness scales and sixteen completed all body weight measurements and blood draws. Thirteen subjects participated in the BLM fitness challenge. Three subjects were excluded from data analysis due to incomplete blood samples resulting from illness or injury.

Table 1. Descriptive Statistics

Characteristic		n
Age (year)	29.0 ± 1.1	21
Height (cm)	180.3 ± 1.9	21
Body Weight (kg)	79.1 ± 2.5	20
Body Fat (%)	15.8 ± 1.5	20

Values are represented as mean ± SEM.

Body Composition

There was no significant change in BW from Day 1 to Day 11 ($p=0.07$) (Table 2). Similarly, there was no effect of time on BW over the course of the training period (Figure 3, $p=0.09$). However, there was a significant increase in BMI ($p=0.044$) and a significant decrease in body fat % ($p=0.001$) from Day 1 to Day 11 (Table 2).

Table 2. Body Composition Alterations

	Day 1	Day 11	P
Body Weight (kg)	79.4 ± 2.7	79.9 ± 2.6	0.065
BMI ($\text{kg}\cdot(\text{m}^2)^{-1}$)	24.4 ± 0.6	24.6 ± 0.6*	0.044
Body Fat (%)	15.2 ± 1.4	13.9 ± 1.3*	0.001
Lean Body Weight (kg)	67.3 ± 2.3	68.8 ± 2.2*	<0.001

Values are represented as mean ± SEM (n=18). * indicates significant different from Day One ($p<0.05$).

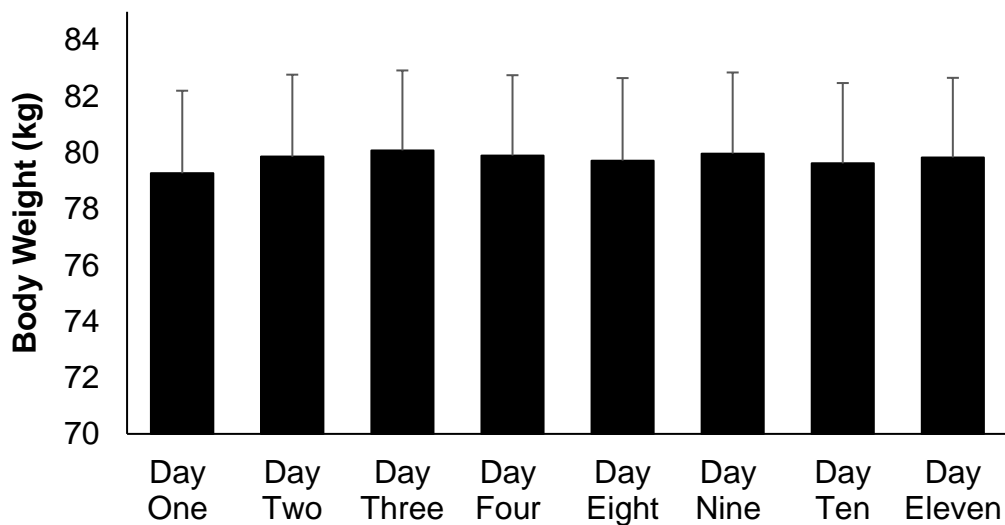


Figure 3. Body weight (n=16). Values are reported as mean ± SEM.

Training Questionnaire

Twenty subjects completed the pre-season preparedness questionnaire. The results are seen below in Table 3. Correlations were run to determine relationships with off-season training and markers of fitness, overtraining, and muscle damage. Specifically, time spent preparing for the season, days of training per week, duration of training sessions, and days of anaerobic/aerobic training per week were included as variables (Table 4).

Table 3. Training Questionnaire Responses

	Number ± SEM or n (%)
Time spent preparing for season (months)?	3.9 ± 1.0
Days of training per week?	4.6 ± 1.3
Duration of training sessions (minutes)?	87.0 ± 28.2
Number individuals involved in session?	
<i>Individually</i>	12 (60%)
<i>Individually, sometimes with partner/group</i>	7 (35%)
<i>Individually or with a group</i>	1 (5%)
<i>With partner most of the time</i>	0 (0%)
<i>With a partner/group, rarely individually</i>	0 (0%)
Location of physical training	
<i>Home</i>	0 (0%)
<i>Outdoors</i>	8 (40%)
<i>Work facility</i>	0 (0%)
<i>Fitness Center (gym membership)</i>	12 (60%)
<i>Fitness classes</i>	0 (0%)
Did workouts typically consist of warmup and cooldown each lasting 5-15 minutes?	
Yes	12 (60%)
No	8 (40%)
Days anaerobic training per week?	2.7 ± 1.4
Days aerobic training per week?	3.0 ± 1.2
Forms of physical activity in training?	
<i>Running</i>	18 (90%)
<i>Weightlifting</i>	17 (85%)
<i>Hiking w/o weight</i>	13 (65%)
<i>Hiking w/ weight</i>	17 (85%)
<i>High-Intensity Circuit Training</i>	12 (60%)
<i>CrossFit</i>	9 (45%)
<i>Swimming</i>	3 (15%)

<i>Biking (Mountain/road/touring)</i>	10 (50%)
<i>Recreational sports/activities</i>	11 (55%)
<i>Yoga</i>	7 (35%)
<i>Plyometric</i>	6 (30%)
<i>Recovery workouts</i>	5 (25%)
<i>Flexibility/stretching</i>	16 (80%)
<i>Other: rock climbing, physical therapy, kettlebells, ski touring</i>	1 (5%)
Goal(s) of physical training	Variable
Previous 48 hours activity	
<i>No</i>	8 (40%)
<i>Light</i>	7 (35%)
<i>Moderate to High</i>	5 (25%)

Values are represented as mean ± SEM or n (%) (n=20).

BLM Fitness Challenge

Raw and scored results of the BLM fitness challenge are below in Table 4.

Table 4. BLM Fitness Challenge Results

	Push-ups	Pull-ups	Sit-ups	1.5-mile run	Total
Repetitions/ Time (sec)	53.5 ± 4.8	15.3 ± 2.3	76.4 ± 6.7	580.8 ± 10.8	-
Score	59.8 ± 3.2	57.2 ± 4.6	61.4 ± 7.2	51.8 ± 4.7	230.2 ± 15.1
Range of repetitions/ time (sec)	30-85	7-37	36-126	541-647	155-310

Values are represented as mean ± SEM (n=13).

Muscle Soreness

There was a main effect for time in upper body muscle soreness (US), increasing from baseline Day 1, peaking on Day 3 (3.9 ± 1.1 cm), and remaining elevated for the entire training period (Figure 4, $p < 0.001$). There is a corresponding main effect for time in lower body muscle soreness (LS), increasing from baseline, peaking on Day 3 (4.3 ± 0.3 cm), and remaining elevated (Figure 4, $p < 0.001$).

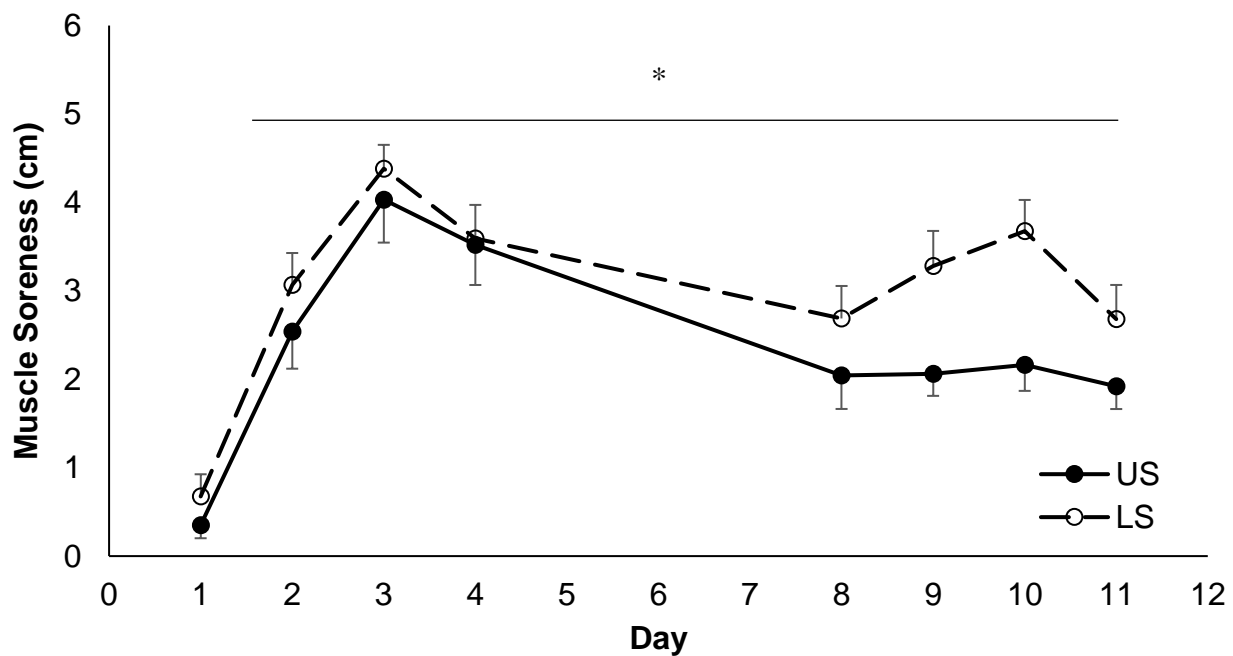
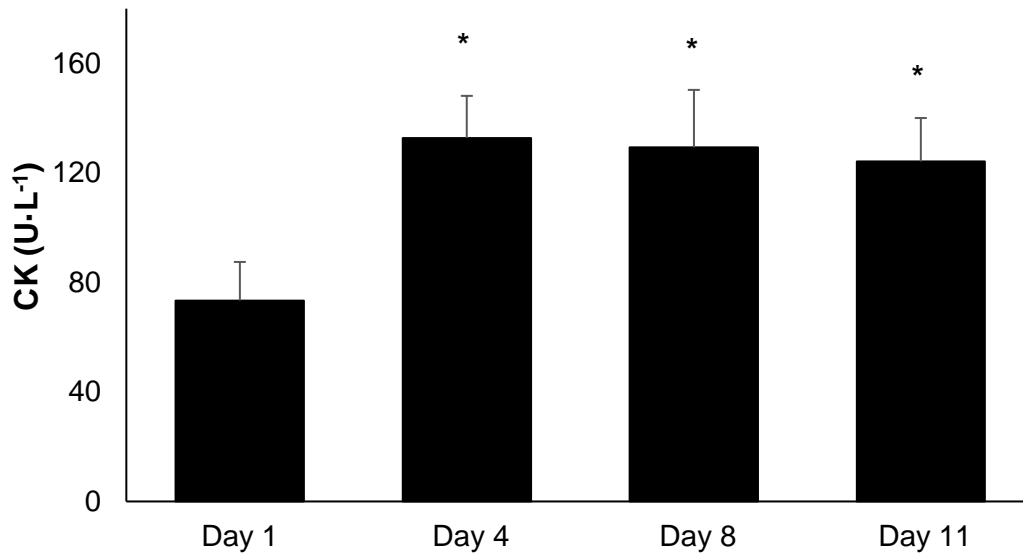


Figure 4. Upper body (US) and lower body (LS) muscle soreness (n=17). * indicates significance ($p < 0.05$) from Day 1. Values are reported as mean \pm SEM.

Biomarkers of Muscle Damage

There was a main effect for time with CK increasing on Day 4 from baseline values, remaining elevated over the entire training period (Figure 5A, $p=0.002$). There was also a main effect for time with LDH increasing on Day 11 compared to Day 1 (Figure 5B, $p=0.04$).

A



B

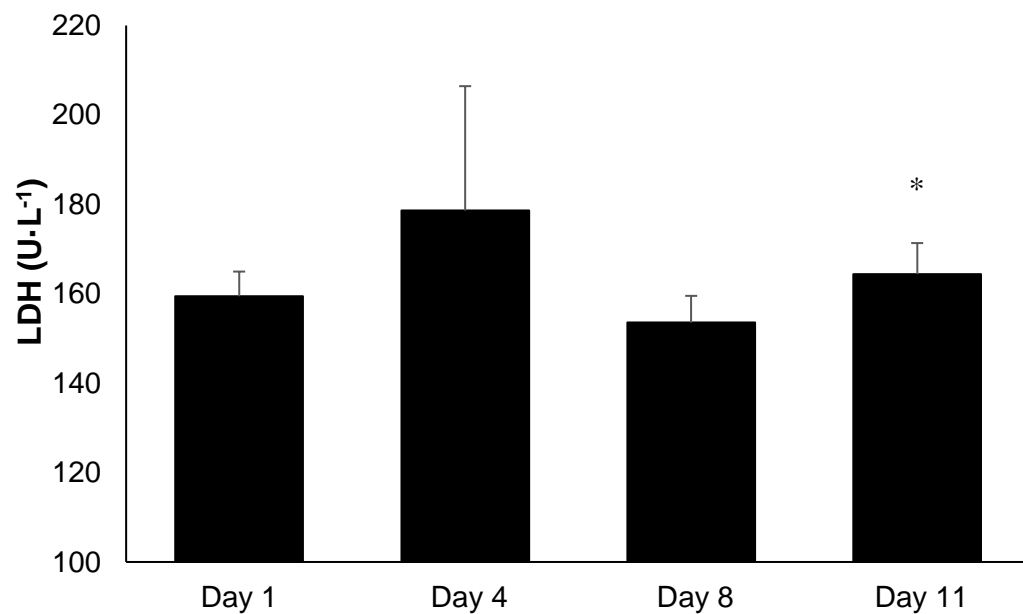


Figure 5. Biomarkers of muscle damage. **A** – Creatine Kinase (n=16). **B** – Lactate Dehydrogenase (n=16). * indicates significance ($p < 0.05$) from Day 1. Values are reported as mean \pm SEM.

C-Reactive Protein

No main effect for time was seen in CRP across the training period (Figure 6, $p=0.32$).

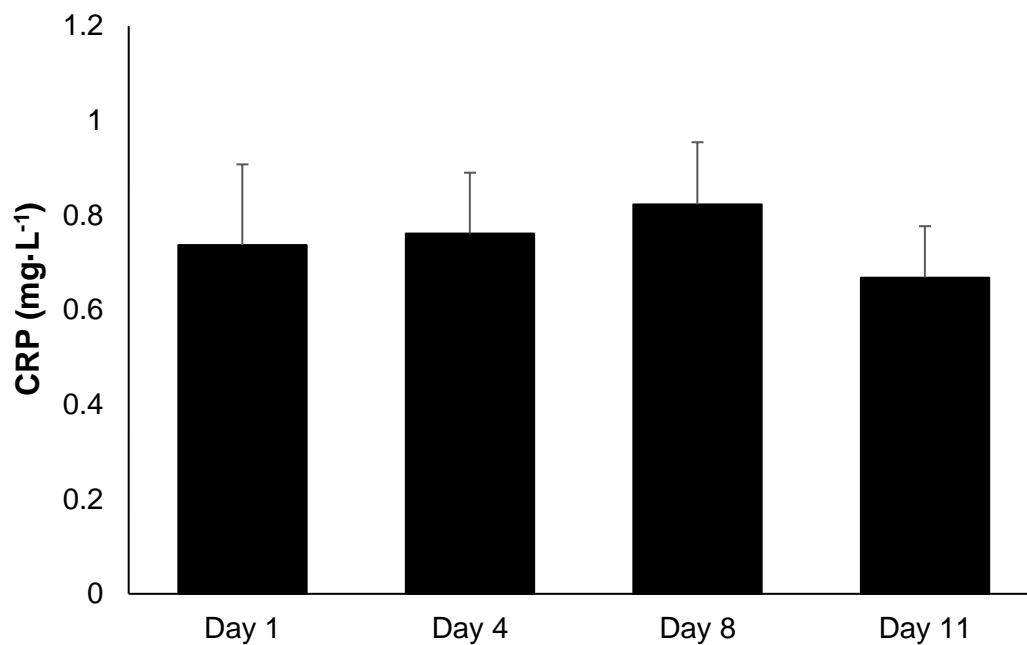
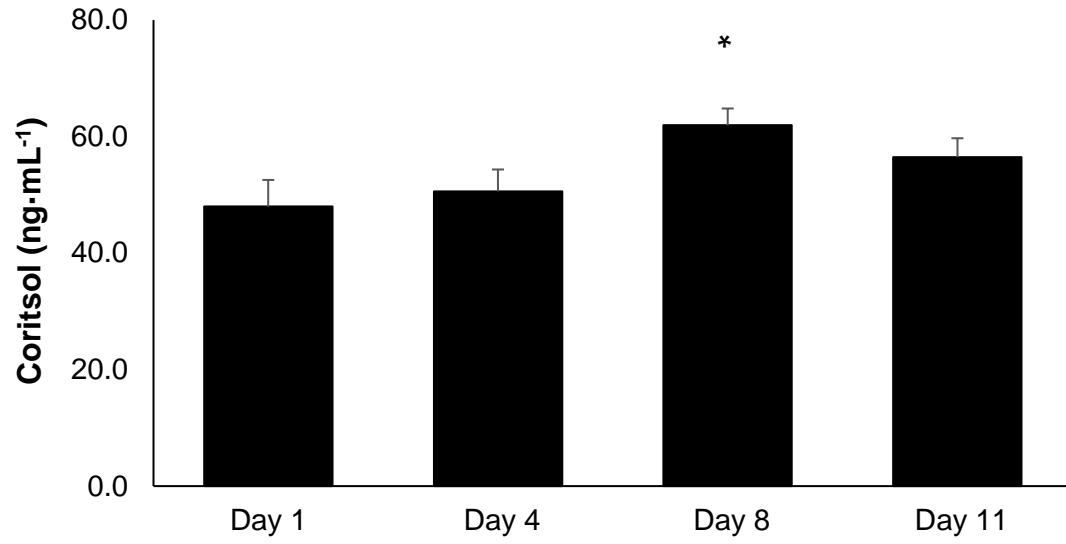


Figure 6. C Reactive Protein (n=16). Values are reported as mean \pm SEM.

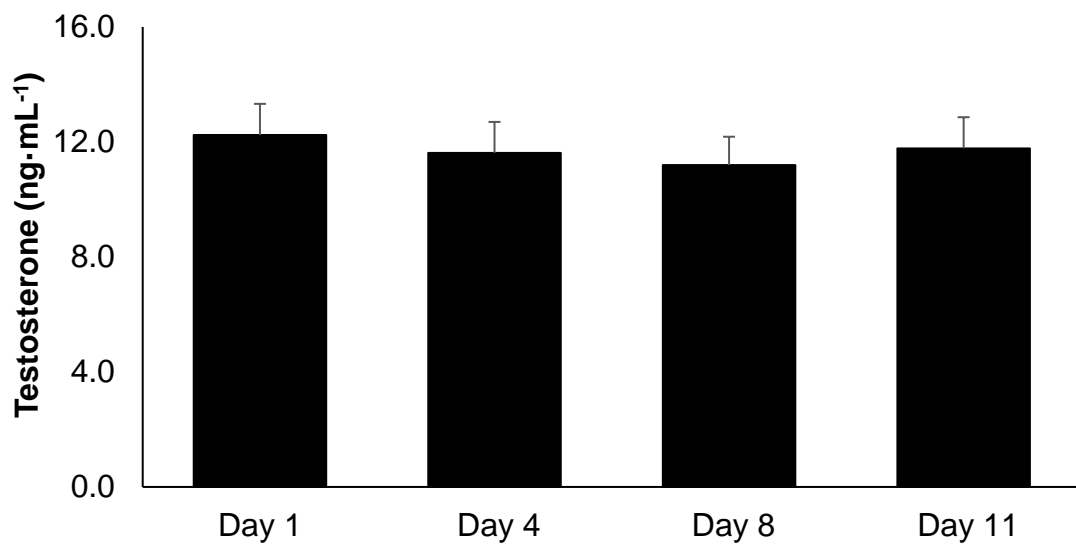
Overtraining

There was a main effect for time with cortisol increasing on Day 8 from baseline values (Figure 7A, $p=0.031$). There was no main effect of time for testosterone over the training period in all subjects (Figure 7B, $p=0.3$). There was a main effect for time with testosterone/cortisol ratio, with the value significantly decreasing on Day 8 from baseline values in all subjects (Figure 7C, $p=0.014$). Results were then differentiated based on sex. There was no main effect for time with testosterone in males ($n=14$) (Day 1: 13.2 ± 1.0 ng·mL⁻¹, Day 4: 12.6 ± 1.0 ng·mL⁻¹, Day 8: 12.2 ± 0.8 ng·mL⁻¹, Day 11: 12.8 ± 0.9 ng·mL⁻¹; $p=0.4$). There was not a sufficient sample size to run statistical analysis in females ($n=2$) (Day 1: 5.9 ± 1.4 ng·mL⁻¹, Day 4: 4.7 ± 0.7 ng·mL⁻¹, Day 8: 4.4 ± 0.6 ng·mL⁻¹, Day 11: 4.5 ± 0.2 ng·mL⁻¹). There was still a main effect for time with the testosterone/cortisol ratio in males ($n=14$) (Day 1: 0.335 ± 0.05 ng·mL⁻¹, Day 4: 0.285 ± 0.03 ng·mL⁻¹, Day 8: 0.203 ± 0.02 ng·mL⁻¹, Day 11: 0.252 ± 0.02 ng·mL⁻¹; $p=0.013$). There was not a sufficient sample size to run testosterone/cortisol ratio statistical analysis in females ($n=2$) (Day 1: 0.098 ± 0.01 ng·mL⁻¹, Day 4: 0.064 ± 0.005 ng·mL⁻¹, Day 8: 0.067 ± 0.008 ng·mL⁻¹, Day 11: 0.064 ± 0.001 ng·mL⁻¹).

A



B



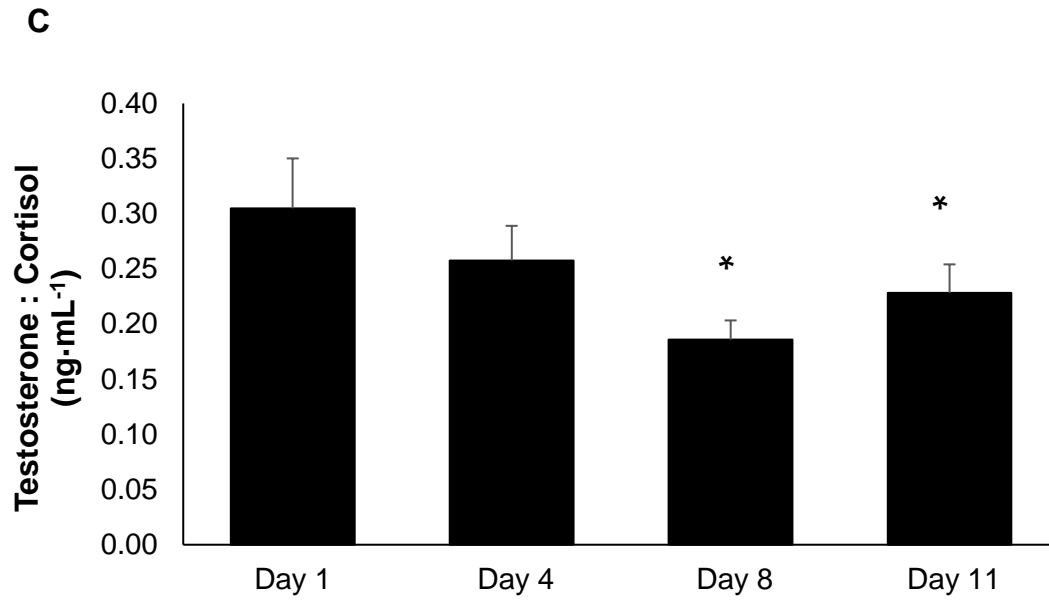


Figure 7. Biomarkers of overtraining. **A** – Cortisol (n=16). **B** – Testosterone (n=16). **C** – Testosterone:Cortisol (n=16). * indicates significance ($p < 0.05$) from Day 1 ($p < 0.05$). Values are for both males and females and reported as mean \pm SEM.

Correlative Relationships

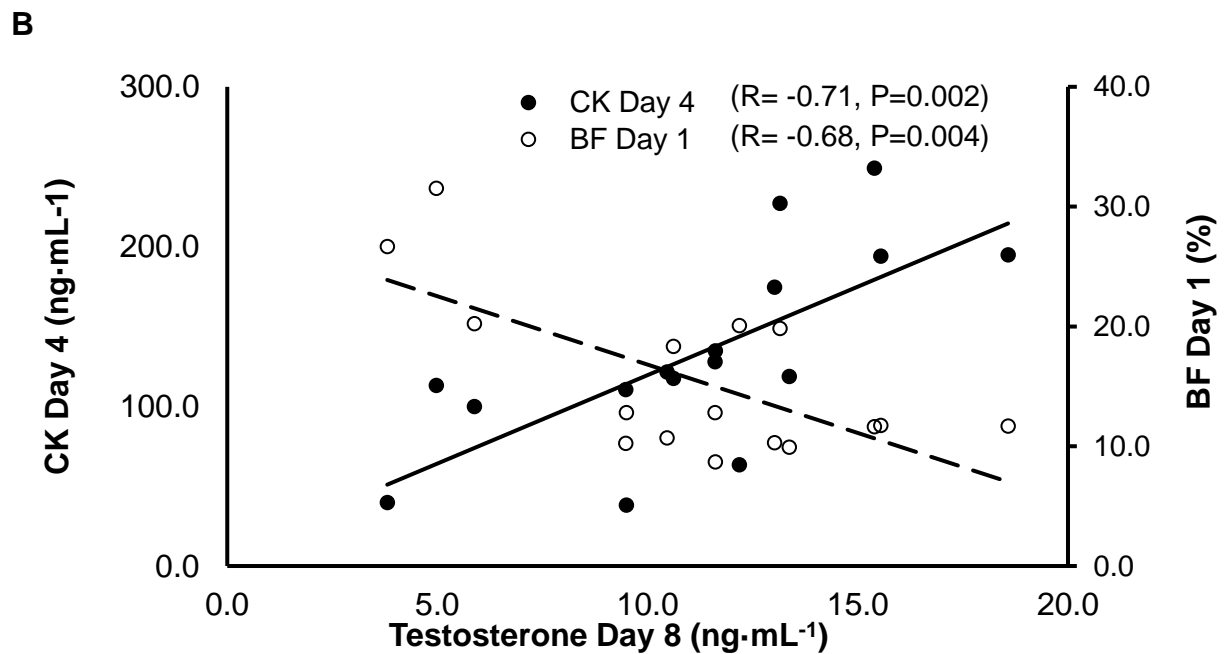
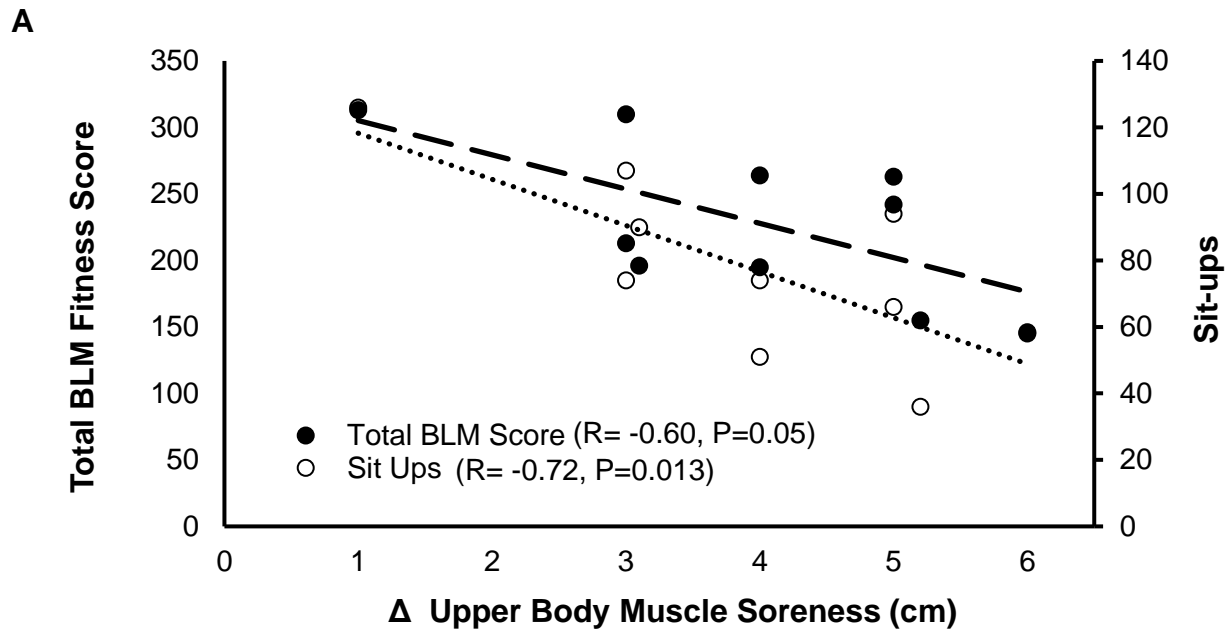
Pearson correlations were run to determine relationships between markers of physiological strain. The results are presented in Table 5. For example, increasing age results in a lesser change in body weight. The associated correlations support the hypothesis that higher fitness has a protective effect against muscle damage, muscle soreness, and overtraining. Fitness was enhanced by adequate pre-season training.

Table 5. Pearson Correlations between Study Markers

		R	P	n
Body Composition				
Age	Δ Body Weight	-0.688	0.003	16
	Δ BMI	-0.697	0.003	16
	CRP Day 4	-0.591	0.016	16
Markers of Overtraining				
Cortisol Day 1	CRP Day 4	0.572	0.021	16
Cortisol Day 8	Age	-0.519	0.04	16
	BMI Day 1	-0.605	0.013	16
Testosterone Day 8	BF Day 1	-0.674	0.004	16
	CK Day 4	0.709	0.002	16
T/C Day 8	Δ US	0.524	0.037	16
BLM Fitness				
Sit-ups	Δ US	-0.72	0.013	11
	Weight Day 1	-0.680	0.021	11
Push-ups	Peak Δ CK	-0.616	0.044	11
	Peak Δ US	-0.643	0.033	11
Run Score	BF Day 11	0.882	<0.001	11
	Δ Cortisol Day 8	-0.605	0.049	11
	Δ T/C Day 8	0.606	0.048	11
Total BLM Score	Δ US	-0.60	0.05	11
Preparedness				
Months preparing for season	LS Day 1	-0.610	0.012	16
	BLM Sit-ups	0.786	0.004	11
Sessions/week training	CK Day 11	-0.518	0.04	16
Days/week anaerobic training	LS Day 4	0.529	0.035	16
	LS Day 10	0.575	0.020	16

Duration of daily training session	Δ BMI	0.543	0.03	16
	BLM Push-ups	0.635	0.04	11
	Total BLM Score	0.828	0.002	11

Δ signifies the change from Day 1 to Day 11. Δ is calculated as Post - Pre values. Data is presented as Pearson correlation (R). Significance was set at $p < 0.05$.



C

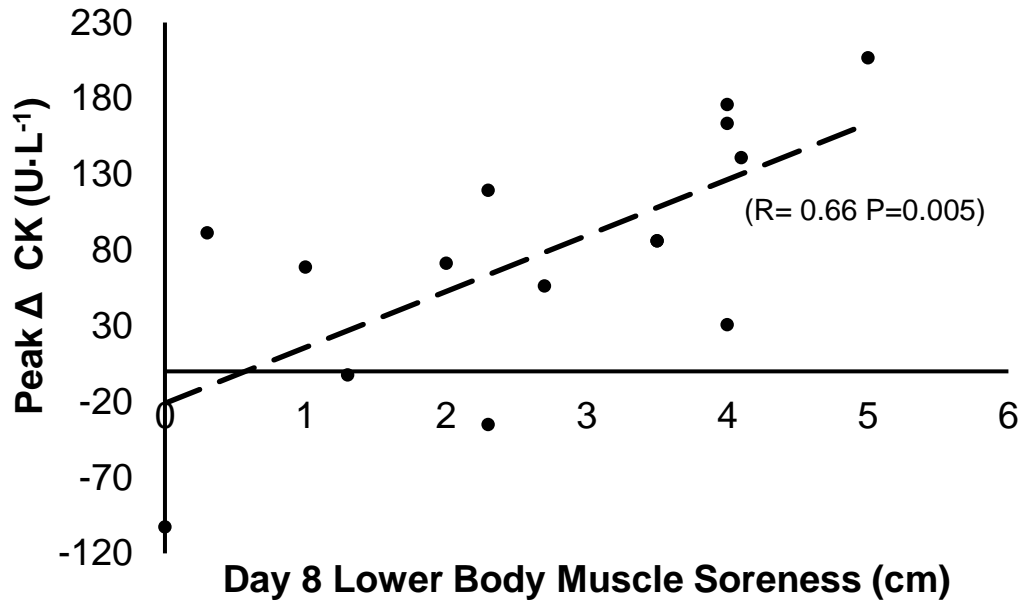


Figure 8. Pearson Correlations. **A** – Δ US vs. Total BLM Score and Sit-ups (n=11). **B** – Testosterone Day 8 vs. CK Day 4 and BF Day 1 (n=16). **C** – Day 8 LS vs. Peak Δ CK (n=16). Values are reported as mean \pm SEM.

CHAPTER FIVE: DISCUSSION

This study examined the effects of a two-week critical training period on markers of muscle damage and soreness in WLFFs. The results demonstrated that CT was a significant stressor to induce physiological changes as WLFFs adjust from off-season training to occupation-specific tasks. To the investigator's knowledge, this is the first investigation of WLFFs during the CT period. Previous literature within occupational stress highlights military training spanning 4+ weeks. This investigation uses a novel approach, examining a relatively short, 11-day training period.

These data indicate that CT is a sufficient stressor to elicit physiological alterations in order to combat the stressor, as evidenced by markers of body weight and composition, muscle damage, overtraining, and soreness. Examining the main measures of interest, we fail to reject the null hypothesis that there will be no change in body weight, but we reject the null hypothesis regarding body composition over the training period. Following analysis of blood plasma, we reject the null hypothesis that there would be no difference in CK and LDH, markers of muscle damage, during the four time points, while we fail to reject the null hypothesis that there would be no change in the inflammatory marker CRP. Additionally, we reject the null hypothesis regarding cortisol and the testosterone/ cortisol ratio, while we fail to reject the null hypothesis regarding testosterone. Finally, we reject the null hypothesis that there would be no change in muscle soreness across CT.

While WLFFs work in conditions that can contribute periods of daily expenditures triple those of resting metabolic rates, the variations in daily work rate and nutrient availability of WLFFs can add to fluctuations in body composition^{6,109}. Previous

research has established an increase in weight, BMI, and total fat mass in WLFFs throughout an entire fire season ¹¹⁰. In this study, there was an observed increase in BMI and trend toward increased body weight, but there was also a marked increase in lean body weight and a decrease in BF, suggesting that the CT period might have a beneficial impact on body weight and composition. The modification of BW and BMI appears to be age-dependent, as increasing age attenuated the alteration and offered a protective effect (Table 5). However, there was a significant decrease in body fat %, with an associated increase in lean body weight, suggesting that any increase in body weight was not due to unfavorable means. More likely, participants experienced a training associated plasma volume expansion ¹⁰⁹.

It is well established that strenuous, unaccustomed exercise can lead to sarcomere disruption, allowing intracellular components to escape to the extracellular fluid and a loss of force production ^{14,15,22,33,46}. This can lead to muscle soreness, and if the damage becomes excessive, it can lead to innumerable health consequences ^{15,22}. Damage can be quantified by using direct muscle biopsy techniques or by less invasive biomarkers. Extensive research indicates that acute bouts of exercise can increase CK significantly, but there is little research on chronic elevations in CK during multi-day training ^{14,51,79}. This study focused on creatine kinase and lactate dehydrogenase as markers of damage to minimize any intervention on day-to-day WLFF activities and to capture any damage compared to a more short-term marker such as myoglobin. These data indicate an increase in muscle damage after the training stimulus of CT, with a significant increase of 45% in CK that remained elevated for the entire two-week period. A rise of 5% was seen in LDH on Day 11, but was a less reliable marker, as the highly

variable clearance rate can result in significant individual discrepancies⁵³. While there is no investigation of CK or LDH in a similar training situation, Al Malki et al. examined serum CK and LDH in Saudi-Arabian firefighters directly post-shift. A similar elevation was observed (63%) in the firefighter group as compared to a normal control group⁶¹. Additionally, a 69% increase in LDH was observed in the firefighter group. However, these data are limited, as there is no baseline value to compare. CRP, a secondary marker of damage that results in inflammation, showed no significant differences throughout CT. Previous research has shown elevations in CRP after extensive exercise bouts, though little examination has focused on continual training sessions. However, chronic elevations in CRP are seen in firefighters exposed to smoke^{69,87}. These data suggest there was biological evidence of muscle damage, though it remained manageable to the WLFF as no secondary inflammation was present during the critical training period.

Muscle soreness can be a vital marker of muscle damage, as perceived pain can impact athletic and occupational performance. In this investigation, soreness was separated into upper-body and lower-body soreness to isolate regions of work, as many extreme muscle damage cases can occur during muscle group-specific work, such as push-ups or squats^{50,54,55}. Our data indicate a significant increase in both upper-body and lower-body muscle soreness, peaking on Day 3, and remaining elevated over the entire eleven-day training. These data parallel work of previous investigations, confirming that delayed onset muscle soreness peaks 48-72 hours after exercise completion, but remaining elevated up to ten days post-exercise. This emphasizes the repeated bout effect, as the subsequent days of training did not elicit additional muscle

soreness that built upon the original soreness^{24,79}. Though subjective, muscle soreness is arguably the most relevant marker of muscle damage, as increased soreness can impede physical performance by causing alterations in muscle sequencing and recruitment patterns due to compensatory mechanisms, resulting in unaccustomed stress on muscle ligaments in tendons and increasing risk of injury¹¹¹. This is crucial to WLFFs, as injury directly impacts occupational performance and safety in field conditions^{11,112}.

A significant increase in plasma cortisol was observed on Day 8 of critical training (the day after a five-day prescribed burn training) simulating field conditions during the WLFF season, then reverted toward baseline values on Day 11. These results mirror research by Szivak et al., who showed a significant increase in cortisol after ten days of Navy SERE training, then attenuated values towards baseline after a 24-hour recovery period¹⁰¹. However, they observed a corresponding attenuation in testosterone values during the same time, while these data show no difference in plasma testosterone. There was a significant depression of the testosterone/cortisol ratio on Day 8, indicating a shift in the anabolic/catabolic state of the body towards the catabolic pathway. Previous research has established that an attenuation >30% indicates poor exercise recovery¹⁰⁵. These data indicate a testosterone/cortisol depression of ~40% from Day 1 to Day 8, suggesting that the simulated field conditions increased physiological stress enough to impede recovery and result in overtraining. Improved body composition was associated with greater testosterone ($R = -0.67$; $p = 0.004$), and lower cortisol ($R = 0.605$; $p = 0.013$) (Table 5). Additionally, these markers of overtraining directly reflected the severity of muscle damage (CK: $R = 0.71$, $p = 0.002$) and soreness (US: $R = 0.524$,

p=0.037). Improper recovery can impact the musculoskeletal system and can result in injury, further impacting WLFF performance in the field.

While many participants that completed the BLM fitness challenge were considered fit (total score >200), elevated fitness appears to have a protective effect on physiological markers of stress in WLFF. Significant correlations suggest a blunted creatine kinase and upper body soreness response during CT with higher BLM fitness scores (Table 5). Additionally, improved aerobic capacity results in decreased cortisol concentration after five days of prescribed burns, and fewer catabolic consequences (Table 5). Ultimately, higher start-of-season fitness appears to improve the physiological ability to handle the stressors of CT. Off-season training is necessary to arrive with adequate fitness. Strong correlations were observed between the amount of time spent pre-season training (months of training: $R=0.79$, $p=0.004$; hours per training session: $R=0.83$, $p=0.002$) and markers of physical fitness (BLM fitness challenge). The higher pre-season training load resulted in lower elevations in markers of muscle soreness and damage ($R= -0.61$; $p=0.012$). Of note, the differentiation between anaerobic and aerobic training was crucial, as those who spent more days focusing on anaerobic exercise resulted in higher lower-body muscle soreness throughout the training period. Adequate fitness and pre-season training habits had positive impacts on the physiological capacity to handle the physical demands of WLFF, emphasizing the repeated bout effect beyond the course of an 11-day training period.

While physiological responses to stress were seen throughout the CT period, an important limitation of the study is the inability to control subject behavior outside of the training period. Before the start of critical training, there was high individual variability in

physical activity levels across the crew, with 40% abstaining from physical activity, 35% maintaining light physical activity (<6 METS), and 25% participating in moderate to high intensity exercise. These variations could account for the inconsistencies seen across the CT period, as participants may have begun CT with preexisting muscle damage and soreness. It is also essential to specify that the occupational stressors of the WLFF shift from day to day, depending on their jobs. While some members of the crew might focus on logistical issues corresponding to fighting fires, others are tasked with digging trenches, resulting in wide ranges of metabolic demand and physiologic stress placed on the body ^{4,6}.

In conclusion, this study confirms that critical training provides a significant physiological stressor to elicit alterations in body composition, muscle damage, soreness, and overtraining. Fitness provides a protective effect on these stresses, and adequate preparation before critical training is crucial to reducing any CT related damage. This protection can help to avoid injury that can incapacitate WLFFs, inhibiting performance and safety during field conditions. While the physiologic responses in this IHC were relatively mild, IHCs are an elite classification of WLFF, and may retain higher levels of fitness in the off season than some lower levels of crews ¹². Additional research of different regional crews with varying degrees of physical fitness and experience is needed to quantify further physiologic patterns that occur during CT. Identifying task-specific damage and the resulting physiologic alterations could lead to a better understanding of the risks WLFFs undergo to prepare for their seasons.

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APPENDICES

Appendix A: Physical Activity Readiness Questionnaire (PAR-Q+)

2019 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

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

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GENERAL HEALTH QUESTIONS

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

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

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

PARTICIPANT DECLARATION
If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for its records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____ DATE _____

SIGNATURE _____ WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

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

Delay becoming more active if:

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

2019 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

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

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

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

2. Do you currently have Cancer of any kind?

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

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

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

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

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

4. Do you have High Blood Pressure?

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

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

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

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

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

2019 PAR-Q+





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

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

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

2019 PAR-Q+




 **If you answered NO to all of the FOLLOW-UP questions (pgs. 2-3) about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:**

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

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

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

 **Delay becoming more active if:**

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

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

PARTICIPANT DECLARATION

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

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that the community/fitness center may retain a copy of this form for records. In these instances, it will maintain the confidentiality of the same, complying with applicable law.

NAME _____

DATE _____

SIGNATURE _____

WITNESS _____

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER _____

For more information, please contact

www.eparmedx.com
Email: eparmedx@gmail.com

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Appendix B: Training Questionnaire



The National Technology and Development Program, in cooperation with the University of Montana, is collecting information on offseason training performed by wildland firefighters (WLFFs). This information will be used to identify common components of WLFF offseason training. Your participation is voluntary, you do not have to respond to all of the questions, and all answers will be anonymous. Please answer each question to the best of your abilities.

1. How long ago did you begin training specifically for this upcoming season?
(Please select one answer only)
 - Less than one month
 - One to two months
 - Two to three months
 - Three to four months
 - Four or more months

2. How many days per week, on average, did your preseason training consist of usually?
(Please select one answer only)
 - One day per week
 - Two days per week
 - Three days per week
 - Four days per week
 - Five or more days per week

3. On average, which was the duration of a daily session?
(Please select one answer only)
 - Less than 30 minutes
 - 30 minutes to 60 minutes
 - 60 minutes to 90 minutes
 - 90 minutes to 120 minutes
 - 120 or more minutes

4. How many individuals were typically involved, or participated, in your workouts? Choose the answer that best describes your training.
(Please select one answer only)
 - Individually or by oneself
 - Individually and sometimes with a partner or group.
 - Individually or with a group.
 - With a partner most of the time.
 - With a partner or with a group, rarely individually.

5. Where did the majority of your physical training occur?
(Please select one answer only)
 - Home
 - Outdoors
 - Work facility
 - Fitness Center (gym membership)
 - Fitness Classes

6. Did these workouts typically consist of a warmup and cooldown session each ranging from 5 to 15 minutes in length?
(Please select one answer only)
 - Yes
 - No

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Wildland Firefighter

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National Technology and Development Program

7. Of those training days per week, how many days were primarily anaerobic (resistance/strength/power/speed) focused?

(Please select one answer only)

Note: If you changed emphasis throughout your training, answer in general terms.

- None
- One day per week
- Two days per week
- Three days per week
- Four or more days per week

8. Of those training days per week, how many days were primarily aerobic (cardio/endurance) focused?

(Please select one answer only)

Note: If you changed emphasis throughout your training, answer in general terms.

- None
- One day per week
- Two days per week
- Three days per week
- Four or more days per week

9. Please select the forms of activity included in your training:

(Please select all that apply)

- Running
- Weightlifting
- Hiking (w/o weight)
- Hiking (w/weight)
- High-Intensity Circuit Training
- CrossFit
- Swimming
- Biking (Mountain/Road/Touring)
- Recreational Sports/Activities
- Yoga
- Plyometric
- Recovery Workouts
- Flexibility/Stretching
- Other(s): Please Specify

10. In your own words, describe the goal(s) of your physical training. Please include specific goals that you may have had to prepare for this season.

11. Please explain what you have been doing physically for the last 48 hours. Include time spent flying, driving, workouts, other exercises, injuries, amount of sleep, etc.

This is the end of the questionnaire. Thank you for your participation.

Appendix C: BLM Instructions (National Interagency Fire Center)

The BLM Fire Operations Fitness Challenge provides a common system by which BLM firefighters can measure current fitness, establish fitness goals, track fitness improvement, and receive recognition for their efforts. The fitness challenge encourages and recognizes achievement in physical fitness by BLM firefighters. The fitness challenge is voluntary, but BLM firefighters are encouraged to participate.

The BLM Fire Operations Fitness Challenge tests participants in four basic exercises - push-ups, pull-ups, sit-ups and a timed run of either 1.5 or 3.0 miles. Test results are compiled into a final overall score. Unit and state offices are encouraged to support and recognize achievement in firefighter fitness. The BLM FA Division of Fire Operations will recognize high achievers annually.

Background

Excellent physical fitness is a essential to firefighter performance. Many times the limiting factor on work production in wildland firefighting is individual fitness. Fatigue has been found to be a contributing factor in many accidents, and numerous studies have proven that physical fitness is a good way to mitigate fatigue. The 2006 study, Contributing Factors for Line of Duty Deaths in the United States (Moore-Merrell, McDonald, Zhou, Fisher, and Moore), concluded that 53.9% of firefighter deaths are due to health, fitness, or wellness. Physical fitness has been addressed as a critical job element in wildland firefighting and is tested with the Work Capacity Test (WCT). However, the WCT is extremely limited in scope, testing only cardiovascular fitness.

Pre-test Requirement

The BLM Fire Operations Fitness Challenge is voluntary. All participating BLM firefighters must meet the physical fitness requirements, medical examination requirements, and DOI Medical Standards Program requirements pertinent to their ICS position. BLM employees who are not firefighters and/or do not hold an arduous ICS fitness rating may participate provided they complete the Health Screening Questionnaire and have no pre-existing medical conditions.

Pre-test Preparation

All entrants should prepare thoroughly for the fitness challenge. Information on proper preparation can be found at www.nifc.gov/FireFit/index.htm.

Test Administration

A medical plan must be in place prior to the test in case first-aid assistance is needed. The number of assistants should be based upon the number of participants. Test administrators shall read a description of each exercise (see below) and

demonstrate proper form prior to the test. The individual test exercises are performed as follows:

Pull-ups: Starting position is hanging from a bar, hands approximately shoulder width apart, arms fully extended with elbows

locked. Hands can be palms away or palms facing the individual. Individual lifts the body until the chin is above the bar and returns to the starting position. This is one repetition. On each repetition the arms must be fully extended and the chin must clear the bar. No kipping or kicking is allowed. Count the number of pull-ups completed in three minutes or when the individual cannot maintain the starting position (lets go of the bar).

Push-ups: Starting position is back straight and parallel with the ground, arms straight with hands approximately shoulder

width apart and elbows locked. Individual lowers the body until the arms form a ninety degree angle and returns to the starting position with the arms fully locked. This is one repetition. The back must remain straight throughout the exercise. All resting must occur in the starting position. The buttocks are not allowed in the air in the starting position. The arms must be fully extended (elbows locked). Count the number of repetitions successfully completed in three minutes or when the starting position can no longer be maintained (arms collapsing, buttocks in the air).

Sit-ups: Starting position is hands behind the ears, back on the ground, legs bent at a forty-five degree angle. Feet can be

held by a person or a fixed object. The individual raises the back until the elbows touch the legs, then returns to the starting position (shoulder blades touch the ground). This is one repetition. Exercise mats may be used for padding. Count the number of repetitions completed in three minutes.

1 1/2 mile or 3 mile run: Conducted on flat, smooth surface.

Exercises may be completed in any order.

Each callisthenic event must be completed within three minutes. Maximum break between callisthenic events is seven minutes. A ten minute warm-up is allowed for the run.

An individual may test multiple times, but scoring will always be based on the results of a single testing event, not on amalgamated individual exercise scores from separate testing events.

Certification

All tests will be administered at the unit level and certified by unit fire management. Unit fire managers seeking national recognition for employees should send pertinent results to their state representative to the national fire operations group (FOG). FOG members should forward those results to **Mike Ellsworth**, BLM Fire Training Unit, no later than July 19.

National Level Recognition and Awards

Achievement in the BLM Fire Operations Fitness Challenge will be recognized nationally in the following categories: Level 1 - 100 points; minimum 20 point per event.

Level 2 - 100 points; minimum 25 points per event.

Level 3 - 200 points; minimum 25 points per event.

Level 4 - 300 points; minimum 25 points per event.

Level 5 - 400 points (max score).

State or Unit Level Recognition

Recognition for achievement in the BLM Fire Operations Fitness Challenge will be through a mid-summer Information Bulletin and distributed through the state's FOG representatives.

Appendix D: Scoring Rubric for BLM Fitness Challenge

BLM Fire Operation Fitness Challenge Score sheet

3 Mile	1.5 mi	Pull ups	Push ups	Sit ups	Points
32.00	15.00	1	15	20	1
31.43	14.50	1	15	21	2
31.27	14.40	1	16	22	3
31.10	14.30	1	16	22	4
30.53	14.20	2	17	23	5
30.37	14.10	2	17	24	6
30.20	14.00	2	17	25	7
30.03	13.50	3	18	26	8
29.47	13.40	3	18	27	9
29.30	13.30	3	19	27	10
29.13	13.20	3	19	28	11
28.57	13.10	4	20	29	12
28.40	13.00	4	20	30	13
28.23	12.50	4	20	31	14
28.06	12.40	5	21	32	15
27.50	12.30	5	21	32	16
27.33	12.20	5	22	33	17
27.16	12.10	5	22	34	18
27.00	12.00	6	22	35	19
26.43	11.50	6	23	36	20
26.26	11.40	6	23	37	21
26.10	11.30	7	24	37	22
25.53	11.20	7	24	38	23
25.36	11.10	7	25	39	24
25.20	11.00	7	25	40	25
25.12	10.56	8	26	41	26
25.05	10.53	8	26	42	27
24.58	10.49	8	27	42	28
24.51	10.46	8	27	43	29
24.44	10.42	8	28	44	30
24.30	10.38	8	28	45	31
24.27	10.35	8	28	46	32
24.23	10.31	8	29	46	33
24.15	10.28	8	29	47	34
24.08	10.24	9	30	48	35
24.01	10.20	9	30	49	36
23.54	10.17	9	30	50	37
23.47	10.13	9	31	50	38
23.40	10.10	9	31	51	39
23.33	10.06	9	32	52	40

BLM Fire Operation Fitness Challenge Score sheet

3 Mile	1.5 mi	Pull ups	Push ups	Sit ups	Points
23.26	10.02	9	32	53	41
23.18	9.59	9	32	54	42
23.11	9.55	10	33	54	43
23.04	9.52	10	33	55	44
22.57	9.48	10	34	56	45
22.50	9.44	10	34	57	46
22.47	9.41	10	34	58	47
22.43	9.37	10	35	58	48
22.36	9.33	10	35	58	49
22.30	9.30	10	35	60	50
22.23	9.28	11	37	62	51
22.16	9.26	11	38	64	52
22.09	9.25	11	40	65	53
22.02	9.23	11	42	67	54
21.56	9.21	12	44	69	55
21.49	9.19	12	45	71	56
21.42	9.17	12	47	73	57
21.35	9.16	12	49	74	58
21.28	9.14	13	50	76	59
21.21	9.12	13	52	78	60
21.14	9.10	13	54	80	61
21.07	9.08	14	55	82	62
21.00	9.07	14	57	83	63
20.53	9.05	14	59	85	64
20.47	9.03	15	61	87	65
20.40	9.01	15	62	89	66
20.33	8.59	15	64	91	67
20.26	8.58	15	66	92	68
20.19	8.56	16	67	94	69
20.12	8.54	16	69	96	70
20.05	8.52	16	71	98	71
19.58	8.50	17	72	100	72
19.51	8.49	17	74	101	73
19.44	8.47	17	76	103	74
19.38	8.45	18	78	105	75
19.31	8.43	18	79	107	76
19.24	8.41	18	81	109	77
19.17	8.40	18	83	110	78
19.10	8.38	19	84	112	79
19.03	8.36	19	86	114	80

BLM Fire Operation Fitness Challenge Score sheet

3 Mile	1.5 mi	Pull ups	Push ups	Sit ups	Points
18.56	8.34	19	88	116	81
18.49	8.32	20	89	118	82
18.42	8.31	20	91	119	83
18.35	8.29	20	93	121	84
18.29	8.27	21	95	123	85
18.22	8.25	21	96	125	86
18.15	8.23	21	98	127	87
18.08	8.22	21	100	128	88
18.01	8.20	22	101	130	89
17.54	8.18	22	103	132	90
17.47	8.16	22	105	134	91
17.40	8.14	23	106	136	92
17.33	8.13	23	108	137	93
17.26	8.11	23	110	139	94
17.20	8.09	24	112	141	95
17.13	8.07	24	113	143	96
17.06	8.05	24	115	145	97
16.59	8.04	24	117	146	98
16.52	8.02	25	118	148	99
16.45	8.00	25	120	150	100