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The Effects Of A Combined Multi-Stressor Environment And Fatigue On Pistol Shooting Performance

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THE EFFECTS OF A COMBINED MULTI-STRESSOR ENVIRONMENT AND FATIGUE ON PISTOL SHOOTING PERFORMANCE

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Chapter 1: Introduction

Occupationally relevant skills including pistol or rifle marksmanship among service members require a combination of cognitive, visual, and neuromuscular coordination (Rifle & Carbine, 2019). Accuracy is an essential parameter of marksmanship and is defined as the distance from the desired point of impact of the projectile and the actual point of impact on the target (Rifle & Carbine, 2019). Training to become a proficient marksman takes several weeks, accruing numerous hours of classroom and field training. Upon successful completion of marksmanship training, service members will have the necessary skills to properly operate and fire small arms weaponry (Grandizio et al., 2014).

Recently, the U.S. Army indicated the need to improve the adaptability of weapon training strategies to meet current and future operational environments (Crowley et al., 2014). The improvement of small arms qualification training by simulating acute environmental changes experienced in austere environments, including heat, cold, and altitude, have been linked to greater success in many past military operations (Rodway & Muza., 2011). Until recently, live-fire training has been the only approved method for small arms field training and marksmanship skill development (Dyer et al., 2010). However, in the latest revision of the U.S. Army's Training and Qualification-Individual Weapons manual released in 2019, electronic weapon simulators are an approved method for use during marksmanship training (Training and Qualification – Individual Weapons, 2019). Training simulators can improve marksmanship performance by providing additional feedback and performance metrics while also increasing the number of practice sessions compared to live fire practice (Mitchell & Brossi, 2016). In addition to improved training efficiency and cost benefits of an electronic-based marksmanship simulator, the practicality, portability, and safety of electronic weapon simulators can provide a costeffective method for testing marksmanship performance within a combination of environments, such as simulated normobaric hypoxia, or various thermal environments within a temperature-controlled room.

Rapid changes to a thermal environment associated with different atmospheric conditions such as temperature, humidity, or pressure related to elevation changes (normobaric or hypobaric hypoxia), can be limiting factors in operational task performance (Muza et al., 2010). Within an occupational or military setting, the ability to perform daily tasks requiring fine motor skills and coordinated movement patterns may be impaired when unacclimated to an environment (Seppanen et al., 2003; Kryskow et al., 2013). For instance, Seppanen et al., 2003 indicated that for each 1°C of thermal change to an environment, there is a reduction in occupational task performance within a thermal range of 25-32°C. Bouak et al., 2018 also indicated that 1-hour of exposure to normobaric hypoxia corresponding to 2,438 m, 3,048 m, 3,658 m, and 4,267 m in un-acclimatized individuals, lead to declines in target identification accuracy and latency during a simulated flight task in military-trained helicopter pilots. Currently, changes in human performance during exposure to combined environmental stressors are lacking and understudied within the field of environmental physiology research (Tipton, 2012; Tipton, 2019). Recent studies have suggested that combined environmental stressors such as hypoxia and cold exposure, can augment exercise capacity during low intensity and high-intensity exercise (Lloyd et al., 2015; Lloyd et al., 2016). Specifically, Lloyd et al., 2015 indicated that 70-min of exposure to combined hypoxia (4,000 m) and cold air (5°C) environment, caused a greater decrease in maximal isometric contraction (MVIC) force (21.4%) that was equivalent to the sum of the reductions in force reported during hypoxia (8%) and cold (14%) independently. In a subsequent study, Lloyd et al., 2016 indicated that 40-min of exposure to hypoxia (4,100 m) and cold air exposure (5°C) reduces time to exhaustion during dynamic leg extensions by 48% compared to a reported 20% decrease due to cold exposure, and a 21% decrease due to hypoxia relative to cold exposure, independently. Interpretation of the two studies (Lloyd et al., 2015; Lloyd et al., 2016) suggests that the magnitude of performance declines during combined hypoxia and cold exposure is equal to the effect on human performance displayed by each stressor independently, thus suggesting that combined exposure of hypoxia and cold may have an additive effect on human performance. (Lloyd & Havenith, 2016). In addition to changes in human performance, Robinson & Haymes, 1990 also indicated that the metabolic effects during combined exposure to hypoxia and cold during exercise can produce greater increases in heart rate, systolic blood pressure, and lactate concentration compared to hypoxia or cold exposure independently.

Human performance degradation during acute hypoxia exposure is primarily related to a decrease in barometric pressure directly altering the partial pressure of oxygen (PO_2), or a decrease in inspired oxygen concentration (fraction of inspired oxygen; F_IO_2) produced during simulated normobaric hypoxia (West, 2012; Musmanno et al., 2017). Decreases in either PO_2 or F_IO_2 leads to autonomic dysregulation, this serves to alter sympathetic reflex responses (heart rate, blood pressure, and circulatory function) which limits aerobic and anaerobic exercise performance (Robinson & Haymes, 1990; Saito et al., 2005; Buchheit et al., 2004). Compensatory mechanisms such as the hypoxic ventilatory response (HVR) becomes elevated in lowland residents subjected to high altitude conditions (Cymerman & Rock, 2009). Increased ventilation improves the oxygen-carrying capacity of blood by hemoconcentration (Naeji, 2010) which can be tracked non-invasively through near-infrared spectroscopy (NIRS) (Scheeren et al., 2012; Subduhi et al., 2007; Scott et al., 2018). During aerobic exercise, hypoxia has been proposed to alter the central motor output, leading to decreases in time to exhaustion and overall aerobic performance during self-paced aerobic exercises at simulated altitudes of 5,000 m (Amann et al., 2006; Jeffries et al., 2019; Mira et al., 2020). Acute hypoxia exposure to 3,600 m (<1-hour) has also been shown to have no influence on isokinetic strength of the knee extensors (Ivamoto et al., 2014), decrease maximal voluntary force contractions, and decrease time to exhaustion during sub-maximal constant dynamic leg extensions (Fulco et al., 1996).

Acute cold exposure has been reported to degrade muscular performance through alterations in the neural muscular signaling cascade (Denys, 1991; Wakabayashi et al., 2015), and the mechanical elastic properties of the muscle (Oksa et al., 1997). Specifically, acute exposures to cold can cause a decrease in dynamic muscular endurance (Oska et al., 2002; Lloyd et al., 2016) and isometric endurance contractions (Hoelwijn & Heus 1992; Thornley et al., 2003; Lloyd et al., 2015), but not isometric peak torque values (Hoelwijn & Heus, 1992; Thornley et al., 2003) between cold exposure ranging from 1.8°C to 10°C for durations between 30-min to 60-min. Overall, much of the research on cold exposure and neuromuscular function has been performed during low-intensity contractions (10-40% MVIC) and during hand grip and forearm flexion tasks (Clarke et al., 1958; Petrofsky & Lind 1980; Petrofsky & Laymon 2005; Oksa et al., 2002; Lloyd et al., 2015). Further investigation is needed to determine the neuromuscular response that will occur during systematic cooling on larger muscle groups (i.e., vastus lateralis [VL]) during greater intensity dynamic movements.

The interplay between cold temperature and neuromuscular degradation has demonstrated a dose-response relationship with a greater decrease in muscular and skin temperature resulting in greater rates of deterioration in muscular performance (Oksa, 2002; Racinas & Oksa, 2010; Wakabayashi et al., 2015). During the first few minutes of exposure to a cold environment, a peripheral skin vasoconstriction reflex response occurs that reduces skin blood flow to preserve metabolic heat (Brown et al., 2003). Changes in localized skin temperature by using thermal imagery have previously been used to monitor acute changes to the microvascular system of the hands, arms, legs, torso, and head in real-time (Ring & Anmer, 2012). For example, Zlatar et al., 2015 found a 3.30°C and 1.76°C decreases in the right- and left-hand skin temperatures of industrial workers following 45-min of exposure to a 10°C environment, while completing a repetitive occupational psychomotor task, respectively. Heus et al., 1995 reported that localized cooling, resulting in a skin temperature of ~ 15°C is the critical threshold for affecting dynamic work performance within the hands. Similarly, previous research has also suggested that finger temperatures below 15°C may also lead to significant dexterity and performance declines (Gaydos & Dusek, 1958; Daanen, 2009).

The loss of hand dexterity and finger coordination due to acute cold exposure is of primary concern to service members where common operational tasks such as fixing equipment, patient transport, and operating a weapon may be hindered (Castellani et al., 2018). According to Heus et al., 1995, decrements in hand dexterity due to cold temperature exposure are related to changes in joint mobility and nerve conduction velocity altering motor task ability. Specifically, during short-term localized cooling (<1 hour), it has been reported that decreased skin temperatures within the hand will cause a reduction in motor task performance within the hands (Giesbrecht et al., 1995) leading to alterations in complex tasks that require speed and precision (Enander, 1987), which are all vital factors for quality marksmanship performance.

Exercise work capacity and muscular performance in hypoxic and cold environments have been reported to independently decrease marksmanship performance (Evans, 1966; Tharion et al., 1992; Tikusis & Keefe, 2007; Moore et al., 2013). For example, acute hypoxia exposure (< 3 days) has been shown to generally degrade pistol and rifle accuracy with altitudes between

3,000 – 4,000 m resulting in the greatest decrements in shooting performance (Evans, 1966; Tharion et al., 1992; Moore et al., 2013; Kryskow et al., 2013). In addition, acute cold exposure has been shown to result in variable responses in marksmanship. For instance, Lackie et al., 1995 displayed an improvement in shot group accuracy in pistol marksmanship when the forearm was subjected to localized cooling for 10-min in a water bath. Additionally, exposure to cold air conditions between 0°C – 5°C for periods between 120-min to 165-min displayed no degradation in rifle marksmanship or target identification (Reading et al., 1994; Tikusis & Keefe, 2002; Tikusis & Keefe, 2007). Based on the previous research it is currently unclear how cold air exposure will influence pistol marksmanship and how systematic cold air exposure may elicit different results in pistol marksmanship compared to localized cold exposure (Lackie et al., 1995). Additionally, thermal effects on marksmanship shown during rifle marksmanship (Reading et al., 1994; Tikusis & Keefe 2002; Tikusis & Keefe, 2007) may be different due to the mechanical difference in the pistol compared to a rifle such as lighter weight, shorter sight radius, and decreased anchor points which may alter shot dispersion and firearm stability (McHale, 2016)

Independent of the effects of hypoxia or cold exposure on marksmanship, moderate exercise and exercise-induced fatigue have been shown to decrease rifle marksmanship performance (Rice et al., 1996; Evans et al., 2003; Moore et al., 2013), improve rifle marksmanship performance (Tenan et al., 2017) or have no effect on pistol or rifle marksmanship performance (Evans, 1966; Tikuisis & Keefe, 2005; Brown, 2011). When hypoxia and exercise were combined, rifle marksmanship decreased between altitudes of 3,000 – 4,300m (Tharion, 1992; Moore et al., 2013). The combined effects of exercise during hypoxia leading to a reduction in oxygenation saturation (SpO_2) may exacerbate strenuous exercise, which may diminish cognitive function, psychomotor performance (Moore et al., 2014), or postural stability during marksmanship tasks (Wagner et al., 2011; Sadowska et al., 2019).

A major obstacle that service members may face during an enlistment term, is rapid deployment to training facilities or designated mission locations that differ from their normally inhabited environments. Of particular importance, rapid insertion into mountainous combat zones, such as the Afghanistan Hindu-Kush region, may pose a new rugged landscape where thermal extremes (summer temperatures of 49°C in northern valleys and winter temperatures of less than 10°C) and altitude conditions between 2,000 – 3,900 m are common (O'Connor et al., 2019). Therefore, it is likely that more than a single environmental stressor will occur simultaneously, potentially degrading the physiological and psychological processes at an exponential rate compared to a single environmental stressor. Therefore, the purpose of this study is to examine the effects of fatigue in cold hypoxic, and cold normoxic environments on pistol shooting performance, thermoregulation, skeletal muscle oxygenation, and maximal and dynamic muscular performance. To the best of our knowledge, this is the first study to evaluate changes in pistol marksmanship when exposed to a multiple stressor environment (simulated hypoxia: 3,600 m [F_IO_2 = 14.3%] and cold air temperatures: 10°C) independently and in conjunction with exertional task fatigue.

Based on the culmination of previous research, it is hypothesized that combined exposure to acute hypoxia and systematic (need to define what *"systematic"* means) cold air will lead to greater decrements in pistol marksmanship and pistol shooting performance compared to cold exposure alone, independent of fatigue. Combined environmental exposure with the addition of fatigue will produce the greatest reductions in pistol marksmanship and shooting performance compared to the non-fatigued condition. Additionally, it is hypothesized that the combined environmental exposure of cold and hypoxia will cause larger decrements in maximal and dynamic muscular performance than cold exposure alone. Specifically, combined environmental exposure will 1) reduce the number of repetitions during the fatiguing dynamic task; 2) decrease maximal isometric force, and 3) produce detectable changes in skeletal muscle oxygenation saturation within the VL compared to cold exposure alone. Lastly, it is hypothesized that combined hypoxia and cold exposure will produce a greater reduction in finger temperature, hand temperature, and muscular hemodynamic response throughout the duration of the exposure period compared to cold exposure alone.

Chapter 2: Literature Review

2.1 Cardiopulmonary Alterations During Acute Hypoxic Exposure

Saito et al., 2005

The purpose of this study was to assess the correlation between arterial oxygen saturation (SpO_2) and heart rate variability (HRV) in order to understand the autonomic dysregulation that occurs during ascent to higher altitudes. Twenty-one subjects (8 males and 13 females; age: mean ± SD = 31 ± 10 yrs) with no formal exercise training, and no previous exposure to altitude conditions above 2,000 m within the past year, embarked on a 4-hour trek. The trek began by subjects reaching 2,100 m by car followed by an ascent of 1,356 m without a weight load. Once the desired altitude was reached (3456 m) subjects completed a 2-hour rest period prior to experimental measurements. An electrocardiogram was used to identify changes in the R-R interval to determine HRV. Arterial blood oxygen saturation was recorded from a probe on the right finger while subjects were resting in the supine position. Changes in SpO_2 and HRV were compared to baseline measures. Results from the study indicated an 18% decrease in SpO_2 values when trekking to altitude with a concomitant 53% increase in resting heart rate values. Additionally, SpO_2 displayed a significant positive correlation with HRV ($r = 0.518$). The authors concluded that acute exposure to altitude can cause blunting of the autonomic response among subjects. The authors also noted that measuring HRV may be more sensitive to hypoxia than clinical symptoms at high altitudes.

Buchheit et al., 2004

The purpose of this study was to investigate the heart rate variability response to acute hypoxia at rest and exercise. Twelve moderately trained male subjects (mean; age: mean ± SD =

31 ± 2.3 yrs) who lived at sea level took part in the study protocol. The protocol began with a 6-min rest period in normoxic conditions followed by another 6-min rest period at hypoxic conditions. To induce hypoxia, an oxygen generator reduced the ventilatory gas mixture to 11.5% O_2 which is equivalent to an altitude of 4,800 m. Following the rest periods, the subject performed a ramp protocol on a cycle ergometer pedaling at a rate of 60-70 revolutions per min. The cycle ergometer load was increased up until the point where the subject reached a heart rate corresponding to 50% of their estimated VO_2max. Following exercise in the hypoxic condition, the oxygen generator was set back to normoxic conditions where subjects performed the identical exercise protocol. Results from the study indicated a significant increase in heart rate, an 8% change in SpO_2 values, and a decrease in HRV when comparing the hypoxic rest period to the normoxic rest period. When comparing the exercise conditions, there was a 19% change in SpO_2 with a similar decrease in HRV between exercise during normoxic and hypoxic conditions. The authors concluded that trained subjects displayed a decrease in vagal-related HRV during acute hypoxia exposure at rest. Additionally, the similar reduction in HRV between exercise conditions was most likely due to the influence of exercise with no additional effect of acute hypoxia.

Fauhaber et al., 2020

The purpose of this study was to investigate differences in submaximal exercise responses during acute exposure to normobaric hypoxia (NH; fraction of inspired oxygen = 15%, corresponding to 3,150 m) versus hypobaric hypoxia (HH; 3,150 m terrestrial altitude). Eight recreationally trained male subjects (mean; age: mean ± SD = 23 ± 3 yrs) took part in a sub-maximal graded cycle ergometer exercise set to three different consecutive intensity levels (100, 150, and 200 W) during each condition (NH and HH). Cardiorespiratory parameters, arterial oxygen saturation, and blood lactate concentration were measured during each condition. Results from the study indicated a small difference in minute ventilation, suggesting ventilation is 1.13% greater during HH compared to NH across exercise intensities (100, 150, and 200 W) during 1-hour of altitude exposure. Additionally, the HH condition displayed a more pronounced lactate accumulation compared to NH during different exercise intensities suggesting a difference in lactate kinetics between the two conditions. The authors concluded that cycling during acute exposure to NH displays an equivalent cardiorespiratory response to HH.

2.2 Alterations in Muscular Strength and Endurance During Acute Hypoxic Exposure

<u>Amann et al., 2006</u>

The purpose of this study was to identify how changes in arterial oxygen content (C_aO_2) can affect peripheral fatigue and the rate of metabolite accumulation that relates to central fatigue and endurance performance. Eight trained male cyclists (age: mean ± SD = 22.5 ± 1.7 yrs) took part in the study protocol. Baseline VO_2max and peak workload (W_{peak}) were determined from a preliminary 5 km time trial and a maximal incremental test on a cycle ergometer. Time trial protocol consisted of four separate 5 km cycling time trails performed while subjects were exposed to normoxic (fraction of inspired oxygen [F_IO_2] = 21%); hypoxic, F_IO_2 = 15%; iso-oxic, F_IO_2 = 24%-30%; hyperoxic F_IO_2 = 100 conditions. To assess quadricep muscle function and performance electromyographic (EMG) activity of the vastus lateralis (VL) was recorded during all time trials. Additionally, a constant-load trial was performed until volitional exhaustion in conditions reflecting similar normoxic, hypoxic, and hyperoxic conditions as previously mentioned. Results from the study indicated that performance on the time trails was consistent among the subjects reflecting a 4-8% increase in timed performance during hypoxic conditions with a 3-6% and a 1-5% reduction in time performance in hyperoxia and iso-oxic conditions when compared to normoxic conditions, respectively. Additionally, mean power output during the time trial was relatively similar throughout normoxic, hyperoxic, and iso-oxic conditions. However, during hypoxia, the power output was drastically reduced during the initial 3 km and remained low throughout the final 2 km of the trial. Results from the average integrated EMG (iEMG) from the VL during the entire time trial indicated that iEMG activity was reduced by 28.4% compared to normoxic conditions. Results from the time to exhaustion protocol indicated a reduction of 44% from normoxia to hypoxia and a 131% increase from normoxia to hyperoxia. The authors concluded that changes in C_aO_2 are significant factors that alter central motor regulation during exercise to prevent the development of peripheral muscle fatigue. Additionally, the authors conclude that hypoxia is a key regulator influencing central motor output and modulating exercise performance such as power output, time to complete the task, and time to exhaustion.

Millet et al., 2009

The purpose of this study was to determine if hypoxia has a direct influence on central drive, independently of factors that occur within the working muscles. Sixteen males (age: mean ± SD = 26.4 ± 5.0 yrs) completed repeated isometric leg extensions during hypoxic and normoxic conditions. During exercise conditions, the air was inhaled from a Douglas bag reflecting an inspired O_2 fraction at 0.11 (simulated altitude: 5,000 m) in hypoxia, and 0.21 in normoxia. In order to evaluate factors that influence central drive beyond the working muscles, a 250-mmHg occlusion cuff was placed on the subjects' thigh during the isometric contractions to induce ischemia to create a similar metabolic state within the working muscle resulting in similar afferent feedback. Therefore, a total of four exercise conditions were completed consisting of: normoxia without the cuff (NWO), normoxia with the cuff (NW), hypoxia without the cuff (HWO), and hypoxia with the cuff (HW). The exercise protocol began with three maximal voluntary isometric contractions (MVIC's) performed for the leg extensors on an isokinetic dynamometer. Following a 3 min rest, subjects were then asked to perform a muscular contraction at 50% of MVIC for 10s using visual feedback followed by another MVIC contraction at the same intensity but instructed to hold for as long as possible to evaluate muscular endurance. The MVICs and isometric holds were performed during each condition (NWO, NW, HWO, and HW). Electromyographic root mean square (EMG RMS) and median frequency (EMG MF) were recorded from the vastus lateralis (VL), vastus medialis (VM), and biceps femoris (BF) during isometric leg contractions. Additionally, arterial oxygen saturation was measured from the earlobe, and lactate was measured and recorded throughout the exercise protocol. Results from the study indicated peak torque values between all conditions were relatively similar throughout each condition. However, the time duration during the isometric contraction hold was reduced by 27% and 17% when comparing NWO to HWO and NW to HW, respectively. Additionally, the decline in isometric peak torque was more pronounced in the HWO than NWO when compared during the isometric endurance hold. Neuromuscular measurements revealed a fatigue-induced increase in EMG RMS with a concomitant decrease in EMG MF within the VM, VL, and BF, despite no difference between the four conditions. Lastly, arterial saturation was 14% lower following the MVIC holds within the hypoxia conditions compared to normoxia conditions, and lactate values displayed an average 63% increase from pre- to post-exercise trial but did not differ amongst the four conditions. The authors concluded that alterations to the fraction of inspired O_2 can influence the modulation of fatigue by the central nervous system, but the influence is moderate. In addition, the authors suggest that declines in exercise performance due to the onset of fatigue may induce a switch from a predominant peripheral regulation to a central component that is sensitive to hypoxia.

Feriche et al., 2014

The purpose of this study was to investigate the relationship of reduced barometric pressure and changes in air composition on the ability to develop explosive strength in a bench press movement following real versus simulate altitude exposure. Twenty-eight male Olympic combat athletes (age: mean ± SD = 22.8 ± 3.8 yrs) were split into two groups to be tested in normoxic conditions, hypobaric hypoxic conditions (altitude of 2,320 m), and simulated hypoxic conditions (Fraction of inspired oxygen [F_IO_2] = 15.7% corresponding to an altitude of 2,300 m). The bench press exercise was conducted on a Smith machine with a linear position transducer affixed to the end of the barbell. Force-velocity relationships were determined from a progressive load test, using only the concentric phase of the bench press. Results from the study indicated a 5.7% increase in 1-repetition maximum (1-RM) bench press values and a 3.3% increase in maximal power due to faster displacement velocity of the barbell at a given workload from normoxia to hypobaric hypoxic conditions. However, there were no significant changes to maximal strength and power observed between normoxia and simulated hypoxia conditions. The authors concluded that acute exposure to moderate hypoxia led to gains in velocity and power during the bench press movement. Additionally, the authors attributed the improved speed of the movement that only occurred during the hypobaric hypoxic condition, to be more related to the reduced air density than reduced inspired oxygen concentration.

Garcia-Ramos et al., 2016

The purpose of this study was to investigate the effects of acute hypoxic exposure on the force, velocity, and power parameters during a loaded squat jump (SJ) and compare unloaded SJ and countermovement jumps (CMJ) between sea level and altitude conditions. Seventeen international swimmers, consisting of 12 women (age: mean ± SD = 17.7 ± 5.3 yrs) and 5 men (age: mean ± SD = 19.9 ± 3.7 yrs) took part in the study protocol. The experimental protocol consisted of subjects performing 3 maximal vertical jumps using the specific unloaded SJ and CMJ movements. Following the unloaded vertical jumps, subjects then performed an incremental load test for the loaded SJ using a Smith machine with a linear transducer affixed to the end of the barbell. A force platform was used to derive maximal force, velocity, and power from each of the loaded and un-loaded vertical jump tasks. The exercise protocol began at an altitude of 295 m and then repeated at an altitude of 2,330 m within the first 24-hours of altitude exposure. Results from the comparison between SJ and CMJ displayed an average increase in peak values of force (2.4%), power (3.7%), and jump height (3.6%) when comparing altitude conditions to normoxic. Additionally, there was a more pronounced increase in force-velocity parameters in the CMJ movement compared to SJ. Results from the force-velocity relationship during the loaded SJ indicated that there was a 7.6% increase in velocity of the bar on the Smith machine, a 6.8% increase in maximal power, and no change in force when comparing the altitude condition to normoxic. The authors concluded that the rightward shift in the force-velocity curve with a concomitant increase in vertical jump performance can suggest a link between acute altitude exposure and the ability to increase muscular power during high-speed dynamic movements.

2.3 Thermal Regulation and Exercise Response During Acute Cold Exposure

Robinson & Haymes, 1990

The purpose of this study was to determine the metabolic effects of acute exposure to hypoxia and cold environmental stress during rest and exercise. Seven healthy males (age: mean ± SD = 31 ± 3 yrs) performed a sub-maximal cycle ergometer exercise during four environmental conditions: normoxia with an ambient temperature of 25°C (normoxia-neutral, NN); normoxia with an ambient temperature of 8°C (normoxia-cold, NC); hypoxia (12% fraction of inspired oxygen, [F_IO_2]) neutral temperature (hypoxia-neutral, HN); and hypoxia in cold (hypoxia-cold, HC [8°C, F_IO_2 =12%]). Results from the study suggested that hypoxic exposure independent of temperature increased exercise and resting heart rate values and systolic blood pressure. Additionally, blood lactate values in each hypoxic condition were 164% higher post-exercise compared with normoxia conditions independent of temperature. Cold exposure leads to a decreased heart rate during exercise independent of hypoxic or normoxic conditions. Rectal temperatures during hypoxic and neutral conditions were significantly lower in cold conditions compared to neutral conditions at rest and during exercise. Additionally, blood lactate values displayed a 55% and 57% increase during cold exposure conditions compare to neutral temperature conditions following 45-min and 90-min of environmental exposure, respectively. Lastly, subject perception of exertion was rated on average 32% more difficult during hypoxic conditions compared to neutral conditions independent of temperature. The authors concluded that during exercise, exposure to hypoxia in addition to cold temperatures leads to lower core body temperature and increased perception of exertion.

Thornley et al., 2003

The purpose of this study was to identify the relationship between local tissue temperature and its effects on peak torque output and time to fatigue during isometric knee extensions. Nine trained males (age: mean ± SD = 22 ± 3 yrs) performed single-leg isometric leg extensions and an isometric endurance hold at 4 separate temperature interventions: temperate, hot, warm, and cold. The protocol began with three baseline maximal voluntary isometric contractions (MVIC) followed by a 30-min temperature alteration by applying a gel pack to the anterior thigh muscle to manipulate local skin temperature to reflect, temperate (29.5 ± 1.4°C), hot (40.1 ± 0.6°C), warm (35.7 ± 1.3°C), and cold (12.4 ± 2.8°C) conditions. Immediately following the 30-min exposure to the gel-pad, subjects performed three additional MVIC knee extensions followed by a 2-min rest and an isometric knee extension endurance hold set to 70% of the MVIC obtained after temperature manipulation. Results from the study indicated no significant changes in peak torque from baseline to temperature manipulated MVIC's across all four conditions. Torque during the isometric knee extension endurance hold was reduced by 17% in the hot condition and increased by 7% in the cold condition when compared to the temperate condition. Additionally, time to fatigue displayed a strong negative relationship to temperature change (r = -0.98) The authors concluded that local tissue temperature manipulation does not impair peak force production but can reduce muscular endurance.

Hackney et al., 1991

The purpose of this study was to examine changes in anaerobic performance during military field operations (MFO) performed during cold and non-cold environmental conditions.

Sixty-two male U.S. Marine soldiers (age: mean ± SD = 21.1 ± 0.4 yrs) were tested from four different environmental conditions. 1) sea-level neutral temperatures (n=14, 15 to 32°C, 4-days duration); 2) sea level, cold temperatures (n=16, -15 to -3°C, 4.5-days); 3) moderate altitude (2,100-2,900 m), neutral temperatures (n=16, 10 to 30°C, 4.5-days); 4) moderate altitude (2,100-2,900 m), cold temperatures (n=16, -22 to -2°C, 4-days). The experiment protocol consisted of a pre- and post-MFO, Wingate test, and a submaximal, aerobic cycle ergometer test following MFO at four different cold and non-cold environmental conditions. The 4 to 4.5-day long MFO consisted of marches, rock climbing, and infantry combat maneuvers while carrying packs and weapons weighting approximately 25 kg. Results from the study indicated no significant effects to moderate altitude exposure on anaerobic performance variables. Overall, peak power decreased by 4.5% following both cold and non-cold conditions, whereas relative peak power decreased by 9.8% following the cold condition and 1.6% following the non-cold condition as indicated from the Wingate test. Results from the submaximal anaerobic cycle ergometer test indicated that resting energy expenditure (RER) did not change from pre-MFO levels to post-MFO values for the normal condition; However post-MFO RER values were significantly reduced compared to the pre-MFO during the first 6-min in the cold condition. Additionally, there was a pre- to post-MFO decline in exercise blood lactate values, reflecting a 26.8% decline for cold conditions and 24.6% decline for non-cold conditions. The authors conclude that declines in absolute and mean peak power variables coupled with the declines in exercise RER and blood lactate response suggests a limited glucose/glycogen substrate availability was primarily responsible for differences in anaerobic performance variables observed following 4 to 4.5-days of MFO training at cold and non-cold environments.

Oksa et al., 1997

The purpose of this study was to observe the relationship between various levels of body cooling and muscular performance during a drop jump movement. Eight sedentary male subjects (age: mean ± SD = 26 ± 4 yrs). Performed a drop landing from a 40-cm bench onto a force plate and performed a maximal rebound jump following 60-min of exposure to ambient air conditions of 27°C, 20°C, 15°C, and 10°C. Results from the study indicate that exposures to all conditions below 27°C, caused reductions in flight time of the jump, average force production, and take-off velocity. Specifically, when comparing performance from 27°C to 10°C, flight time decreased by 8%, force production decreased by 48%, and takeoff velocity decreased by 18% Additionally, electromyographic amplitude values (iEMG) of the agonist muscle (triceps surae) increased during the drop landing movement, whereas iEMG of the antagonist muscle (tibialis anterior) decreased during the coldest temperature exposure (10°C). Alternatively, the mean power frequency of the EMG signal (EMG MPF) of the antagonist muscle decreased by 34% when comparing the drop landing movement performed at 27°C compared to 10°C. The authors concluded that decrements in muscular performance follow a dose-dependent response with the degree of cooling. Additionally, this dose-dependent response may also exist within EMG changes during various levels of cooling.

Oksa et al., 2002

The purpose of this study was to investigate changes in electromyographic (EMG) activity and fatigue in the forearm flexor muscle when exposed to systemic and local cooling. Eight healthy males (age: mean ± SD = 31 ± 6 yrs) performed six, 20-min work bouts of repetitive wrist flexion-extension muscle actions at 10% maximal voluntary contractions (MVC) at three separate conditions: thermoneutral control (25°C); systemic cooling (5°C); and local cooling (5°C). Results from the study indicated that EMG activity of the forearm flexors and extensors was higher during the systemic cooling condition (31% and 30%, respectively) and the local cooling condition (25% and 28%, respectively) than during the thermoneutral control condition. Additionally, fatigue index (calculated from changes in wrist flexion MVC and amplitude of EMG from wrist flexors during the entire work bout) indicated that repetitive wrist-flexion and extension muscle actions produced 15% fatigue of the forearm flexors, whereas fatigue index was 37% and 20% following systemic cooling and local cooling conditions, respectively. The authors conclude that despite minor differences between systemic and local cooling, repetitive exercise in the cold leads to higher EMG activity and fatigue than a repetitive exercise in a thermoneutral environment.

Daanen, 2009

The purpose of this study was to investigate the relation between decrements in hand dexterity and National Weather Service Wind Chill Equivalent Temperature (NWS-WCET) values to be used as a future indicator for expected dexterity decrements. Twelve healthy males (age: mean ± SD = 27 ± 6 yrs), participated in nine different exposure protocols where the ambient temperature was set to 0, -10, and -20°C and wind speed set to 0.2, 4, and 8 m/s. Immediately after entering the environmental room subjects began performing manual dexterity tests consisting of the Purdue Pegboard test, the Minnesota Rate of Manipulation-Placing test, and maximal isometric grip force on a hand dynamometer every 20 min until volitional thermal discomfort. Results from the study indicated that deterioration in manual performance was strongly dependent upon NWS-WCET and exposure time ($r = 0.93$). Additionally, performance scores on each of the tests seem to show significant decreases when finger temperature drops below 14°C. The authors concluded that NWS-WCET may serve as an indicator for manual performance decreases when used between the temperature range of 1 to -34°C for an exposure period of up to one hour. In addition, the authors suggest that dexterity tasks are well correlated with mean body temperatures especially when finger temperature and toe temperatures are considered within the weighted average equations.

Lloyd et al., 2015

The purpose of this study was to examine the individual and combined effects of exposure to hypoxia and cold on muscle fatigue development in the forearm during repetitive low-intensity contractions. Eight males (age: mean ± SD = 22.1 ± 2.1 yrs), were exposed to four environmental conditions: normoxic cold (5°C, fraction of inspired oxygen [F_IO_2] = 21%), hypoxic cold (5°C, 4,000 m [F_IO_2 = 13%]), normoxic neutral (22°C F_IO_2 = 21%), and hypoxic neutral (22°C, 4,000 m [F_IO_2 = 13%]). Following 70-min of exposure at each condition, subjects performed intermittent dynamic grip clenches at 15% of their maximal isometric voluntary contraction (MVIC) every 2-s for eight consecutive 5min workbouts. Results from the study indicated that independent exposure to hypoxia and cold reduced MVIC force by 8% and 14%, respectively, compared to the neutral condition. However, when hypoxia and cold were combined the decrease in MVIC force was 21.4% greater than neutral. Additionally, electromyographic root mean square (EMG RMS) during MVIC increased by 36% and 23% for cold and hypoxia, respectively. When hypoxia and cold were combined, EMG RMS increased by 56%. The authors conclude that when exposed to a combination of moderate hypoxia and cold, fatigue accumulation (decrease in MVIC force, and increase in EMG RMS) are additive, suggesting that the independent environmental stressors will be equivalent to the effect of the combined stressors.

Lloyd et al., 2016

The purpose of this study was to identify the interaction between environmental temperature and hypoxia on neuromuscular fatigue rates and time to exhaustion during dynamic knee extension movements. Nine moderately trained males (age: mean ± SD = 22.1 ± 2.1 yrs), were exposed to three environmental conditions: Cold (5°C, 50% relative humidity), Neutral (23°C, 50% relative humidity), and Hot (42°C, 70% relative humidity) during sea-level conditions (fraction of inspired oxygen [F_IO_2] = 21%) and simulated altitude of 4,100 m (F_IO_2 = 12.5%). Following 40-min of exposure at each condition, subjects performed submaximal dynamic leg extensions at a rate of 60 extensions/min until volitional fatigue. Results from the study indicated that independent exposure to environmental conditions reduced time to exhaustion by 20%, 42%, and 51% during repetitive leg extension contractions while exposed to cold, hot, and hypoxia, respectively. The addition of hypoxia reduced time to exhaustion by 21%, and 42% compared to relative cold and hot exposure conditions, respectively. However, when compared to the normoxic neutral condition, the combined effects of hypoxia and cold indicated a 48% reduction in time to exhaustion. Alternatively, compared to the normoxic neutral condition, there was a 35% reduction in time to exhaustion during combined heat and hypoxia. The authors concluded that combined exposure to moderate hypoxia and mild cold stress results in an additive relative reduction in time to exhaustion during repetitive knee extension movements. In contrast, moderate hypoxia and heat stress result in a significant antagonist interaction regarding time to exhaustion, indicating the effect of each stressor was attenuated in the presence of the other stressor.

2.4 Hemodynamic Response During Exercise

Taelman et al., 2011

The purpose of this study was to investigate the relationship between surface electromyographic (sEMG) and near-infrared spectroscopy (NIRS) parameters during static isometric and repetitive semi-dynamic muscle actions performed until exhaustion. Forty-eight subjects (24 male, 24 female, age: mean ± SD = 21 ± 2.0 yrs) performed upper-arm isometric and semi-dynamic muscle actions while sEMG (root mean square; RMS and mean power frequency; MPF) and NIRS (tissue oxygenation index; TOI) was measured from the biceps brachii (BB). Subjects performed a seated isometric bicep curl, with the elbow flexed at 90°, and forearm in the supinated position. Subjects were required to hold the contraction set to 50% of their pre-determined maximal voluntary isometric contraction (MVIC) until volitional exhaustion. Similarly, for the semi-dynamic contractions, the subject performed alternating 4 s contractions at 20% of MVIC and 6 s contractions at 60% of MVIC until exhaustion. Results from the study indicated that the semi-dynamic test was significantly longer than the static isometric test indicating muscle fatigue was reach faster during the isometric test. Additionally, there was a linear increasing trend for the sEMG amplitude parameter (RMS) and a linear decreasing trend for the sEMG frequency parameter (MPF) observed for both the isometric and semi-dynamic contraction tests. Results from the TOI revealed a four-phase response pattern in both the isometric and semi-dynamic tests revealing a significant negative correlation between change in TOI (ΔTOI) and exercise time for isometric (r=-0.64) and semi-dynamic exercise (r=-

0.74), indicating higher deoxygenation results in early exhaustion. Lastly, MPF and TOI slope during the initial 25% of the isometric and semi-dynamic protocol were significantly correlated. The authors conclude that sEMG provides information about muscular fatigue as an ongoing linear process whereas NIRS indicates the velocity of the fatigue process. Suggesting both sEMG and NIRS can provide complementary information relating to muscular fatigue.

Subudhi et al., 2007

The purpose of this study was to simultaneously track changes in central and peripheral oxygenation using near-infrared spectroscopy (NIRS) during incremental exercise to exhaustion. Thirteen competitive male cyclists (age: mean ± SD = 30 ± 7 yrs) with recent experience cycling at elevations between 2,500 and 4,300 m, took part in a maximal incremental cycle ergometer test during two separate conditions: normoxic (fraction of inspired oxygen [F_IO_2] = 21%; sea level), and hypoxic (F_IO_2 = 12%; 4,100 m). The NIRS parameters (change in oxy-hemoglobin concentration; Δ[O_2Hb], change in de-oxyhemoglobin concentration; Δ[HHb], and total hemoglobin concentration; Δ[THb]) were measured from the subjects' frontal cortex and left vastus lateralis muscle during both normoxic and hypoxic exercise conditions. Results from cerebral oxygenation indicated that during the normoxic condition, all NIRS parameters increased between 25 to 75% peak power output but Δ[O_2Hb] decreased from 75 to 100% peak power output. Whereas, cerebral oxygenations changes in the hypoxic condition were greater than normoxic condition indicating a progressive decrease Δ[O_2Hb] and Δ[THb] with a concomitant increase in Δ[HHb] in parameters across all work rates, with Δ[THb] increasing at 75% peak power and remained constant. Results from the muscle oxygenation were similar across normoxic and hypoxic conditions indicating a decrease in Δ[O_2Hb] with increases in

Δ[HHb] and Δ[THb] between all work rates until 75% peak power where Δ[O_2Hb] was unchanged. Similar to the cerebral oxygenation pattern, muscle oxygenation displayed a greater change during the hypoxic compared to the normoxic condition. The authors conclude that incremental exercise performance is not limited to changes in cerebral oxygenation during normoxic conditions. However, changes in cerebral oxygenation may play a greater role in limiting the exercise capacity during incremental exercise performed in hypoxia.

Scott et al., 2018

The purpose of this study was to investigate if acute hypoxic exposure during high-load resistance exercise can enhance hemodynamic response (oxyhemoglobin; HbO_2, and deoxy hemoglobin; HHb), or muscle activation (iEMG) related to muscular development. Twelve trained men (age: mean ± SD = 25.3 ± 4.3 yrs) completed high-load squats and deadlifts during three hypoxic conditions: normoxia (fraction of inspired oxygen [F_IO_2] = 21%; sea level), moderate-level hypoxia (F_IO_2 = 16%; 2,106 m), and high-level hypoxia (F_IO_2 = 13%; 3,700 m) while near-infrared spectroscopy (NIRS) and surface electromyography amplitude values (iEMG) were measured from the vastus lateralis (VL) muscle. Results from the study indicated that there was a significant difference between maximal deoxyhemoglobin values in the deadlift between conditions. There was no difference between oxyhemoglobin values between conditions. Additionally, muscle activation during high-load squats and deadlifts did not differ between hypoxic conditions. The authors conclude that high-load resistance training during acute hypoxic exposure does not provide added benefits to physiological responses related to muscular development.

2.5 Infrared Thermography During Hypoxia and Cold

Keramidas et al., 2014

The purpose of this study was to investigate the effects of acute exposure to normobaric hypoxia on hand temperature responses during and after a cold-water immersion test. Fifteen near sea-level male residents (age: mean ± SD = 24.9 ± 3.0 yrs) completed two laboratory conditions consisting of right-hand immersion in 8°C water for 30-min while breathing room air (fraction of inspired oxygen [F_IO_2]) = 21%; sea-level) or a hypoxic gas mixture (F_IO_2 = 14%; 4,000 m). Following the cold-water immersion test, skin temperatures were analyzed through infrared imaging a 15-min rewarming phase in ambient conditions (20.9°C, 35% relative humidity). Results from the study indicated that 30-min of cold-water emersion in hypoxic and normal conditions produced an identical decrease in skin temperature of the hands (12.5°C). Additionally, skin temperatures from all five fingers were significantly lower during the hypoxic condition compared to the normal conditions throughout the 15-min rewarming phase. The authors conclude that acute exposure to normobaric hypoxia does not aggravate cold-induced degradation of the skin temperatures of the hands in males, however, hypoxia plays a role in the rewarming pross of the hand.

Zlatar et al., 2015

The purpose of this study was to identify the influence of moderate cold air temperatures on skin temperatures of the hand during a simulated repetitive occupational task in industrial cold storage workers. Five female workers (age: mean ± SD = 23.0 ± 3.85 yrs) were exposed to 10°C air for a period of 40-min. Three thermal images of the right and left hand were assessed at baseline, 10-min of exposure and 35-min of exposure. Following 10-min of exposure, workers completed 15-min of a repetitive psychomotor task, placing newspaper wrapping over a 1 kg sandbag to simulate a cheese packing process. Upon termination of the psychomotor task, the workers rested for 10-min until the last thermal image of the right and left hand was assessed at the 35-min timepoint. Results from the study indicated that 10-min of exposure produced no significant changes in skin temperatures of the right and left hand. Between 10-min of exposure to 35-min of exposure, skin temperatures of the right hand decreased by 12% whereas skin temperatures of the left hand decreased by 6%. The authors concluded that cold exposure causes a decrease in skin temperature of the hand that is not always consistent across limbs. The authors hypothesized that utilizing the left hand more during the repetitive psychomotor task was the reason for the smaller magnitude of temperature change compared to the right hand during the cold exposure period.

Jones et al., 2018

The purpose of this study was to quantify changes in surface body temperatures of the hand during various levels of normobaric hypoxia to identify the role of hypoxia-induced vasoconstriction response within peripheral blood vessels. Ten healthy male subjects (age: mean ± SD = 24.6 ± 1.8 yrs) took part in an 8-hour graded hypoxia exposure period where four levels of hypoxia (fraction of inspired oxygen [F_IO_2]), were evaluated for a period of 90-min. Baseline 466 m, (F_IO_2 = 20%).1,740 m (F_IO_2 = 17%), 3,270 m (F_IO_2 = 15%), 4,167 m (F_IO_2 = 13%). Skin temperatures of the hand were analyzed at each altitude condition from four anatomical regions: the nail bed, distal interphalangeal (DIP) joint, proximal interphalangeal joint (PIP) and metacarpophalangeal (MCP) joint for both the right and left hand. Results from the 8-hour graded hypoxia exposure indicated that there was an incremental decrease in skin temperature of the hands at each of the four anatomical sites with increasing levels of hypoxia. Changes from baseline to 4,167 m (F_IO_2 = 13%) indicated that the nail bed temperature decreased by 13%, DIP joint by 12%, PIP joint by 11%, and MCP by 6%, whereas no other hypoxic condition displayed a significant change in temperature at the four anatomical sites. The others conclude that exposure to normobaric hypoxia leads to a reduction in skin temperature of the hand detected from four anatomical sites of the phalange.

2.8 Environmental and Muscular Fatigue as Factors Affecting Shooting Performance

Evans, 1966

The purpose of this study was to identify the independent effects of exercise and exposure to acute altitude on pistol shooting performance. Six health males (age: 18-35 yrs) performed two separate sessions ("speed" and "accuracy") of a pistol marksmanship task using a CO_2 pistol. Each marksmanship task required subjects to fire 6 single shots at a target placed 6.4 m away during 4 timepoints: the beginning of the treadmill walking test, and at performance decrement levels of 10%, 20%, and 30%. In addition, eight healthy males (age: 19-25 yrs) with no exposure to an altitude higher than 914 m were taken from sea level to 4,300 m for 19-days to evaluate change in latency and accuracy during a similar pistol shooting task without the treadmill intervention as outlined previously. Results from the two experiments suggested that treadmill walking fatigue produced no change in pistol accuracy but an increase in latency to fire. Additionally, rapid transition to high altitude produced a decrease in both accuracy and latency compared to sea level marksmanship. The authors concluded that fatigue produced a "lethargic" effect resulting in subjects compensating by latency to allow more accurate firing, whereas altitude exposure caused subjects to shoot faster and less accurately.

Tharion et al., 1992

The purpose of this study was to identify the independent and combined effects of altitude exposure and fatigue on rifle marksmanship. Sixteen soldiers (age: 18-39 yrs) who resided below 1,500 m performed a marksmanship task using an inert infrared laser-based M-16 rifle during five different conditions: 1) rest at sea level; 2) immediately following a 21-km run/walk ascent from 1,800 m to 4,300 m; 3) rest during days 1-3 at altitude; 4) rest during days 14-16 at altitude; 5) immediately following the second ascent after 17-days at altitude. Subjects performed a marksmanship task in a free-standing unsupported position firing 2 sets of 5 shots at a stationary target for accuracy, and 2 sets of 5 shots at a stationary target for speed and accuracy at a simulated distance of 100 m for a total of 20 shots per condition. Results from the study indicated that acute altitude exposure in the rested state leads to a 9% increase in distance from center mass compared to sea level conditions in the rested state. Following prolonged exposure to altitude (17-days) improved marksmanship accuracy by 15%. Results from marksmanship performed at attitude and exercise produced a 17% increase in distance from center mass compared to resting altitude marksmanship performance but had no effect on rifle sighting time. Additionally, sighting time and distance from center mass improved to sea-level values following prolonged exposure to altitude (17-days). The authors concluded that exercise and acute altitude exposure can independently affect rifle marksmanship. However, marksmanship can return to sea level values after prolonged exposure at high altitudes.

Reading et al., 1994

The purpose of this study was to examine the effects of cold exposure and muscular shivering on rifle shooting performance. Six male U.S. Marine marksman performed a simulated rifle marksmanship task using an inert M-16 A2 rifle throughout an exposure period of 120-min at ambient air temperatures of 4.4°C (cold condition) or 24°C (neutral condition). During each condition, subjects fired ten shots at a stationary target placed 2.86 m away during four separate timepoints: 25-min, 55-min, 85-min, and 115-min. Results from the study indicated that there were no significant differences in rifle shooting accuracy between cold or neutral conditions, however, horizontal deviations increased by an average of 29% between the 55^{th} to 115^{th} min during cold exposure condition compared to the neutral condition. Additionally, it was observed that 120-min of exposure to 4.4°C caused a significant decrease within the frequency spectrum of the electromyographic signals of the trapezius and mid-deltoid muscles indicating mild shivering was occurring. The authors conclude that mild shivering exhibited by the subjects does not have an adverse impact on rifle shooting accuracy but may lead to deviations in horizontal shot displacement in a highly trained marksman.

Lackie et al., 1995

The purpose of this study was to investigate if temperature-induced changes in the tremor of the hand will lead to improvements in pistol shooting performance in novice individuals. Six subjects (age: mean; 24.8 yrs) with no pistol shooting experience were trained on proper pistol shooting form for several days prior to testing. During each testing visit, the subjects dominant forearm was immersed in a temperature controlled bath for 10-min at either 10°C (cooling condition) or 44°C (heating condition) before performing five shots at a target 8 m away for a series of four rounds (20 total shots), at room temperature conditions between 20-23°C. Results from the indicated that 10-min of cooling reduced the power of the tremor by 40% compared to control condition (20-23°C ambient temperature exposure), whereas 10-min of heating increased the power of the tremor by 55% compared to control condition. Additionally, shot grouping was reduced by 47% in the cooling condition but increased by 61% in the heating condition compared to control. Thus, indicating that shots become tighter with cooling, but become more dispersed with heating. The authors conclude that local cooling can reduce muscular tremor size which can improve shooting performance, especially shot group tightness during a pistol marksmanship task.

Rice et al., 1996

The purpose of this study was to assess the effects of gender, team size, and harness or hand-carry procedure during repeated simulated stretcher carries and its effect on marksmanship. Twenty-three subjects, 12 males (age: mean ± SD = 20.8 ± 2.6 yrs) and 11 females (age: mean ± SD = 23.6 ± 4.0 yrs), took part in the study protocol. The protocol consisted of., stretcher carry tasks which were performed on a treadmill holding a manikin (total weight = 88.6 kg) for 50 m at a self-selected walk/run pace. Immediately following the distance covered, subjects were instructed to step off the treadmill, walk 5 m and lift a weight equal to the patient's load into an ambulance. To simulate team effort on distributing stretcher load, 45-kg reflected effort of a two-man team, whereas 22.5-kg load reflected effort of a 4-man team. The load stretcher drill was repeated as many times as possible within a 15-min period to simulate a mass casualty situation. The drill was repeated using both a harness and hand-carry technique. Following the repeated stretcher carries a marksmanship drill was performed using a laser marksmanship simulator device with an infrared laser M-16 rifle. The 2.3-cm diameter target was presented 5 m away from the shooter. The shooter was instructed to engage the target by firing 20 single rounds while standing in the free-standing unsupported position. Results from the study indicated that distance from the center mass was 3.7% greater when assessed from pre-carry to post-carry independent of the harness or hand-carry technique. Additionally, men carrying the stretcher using the hand-carry technique displayed a more dispersed shot grouping. Lastly, the effect on team size indicated that during post-carry, shot dispersion increased by 10.4% and decreased by 18.7% when comparing a four-person team to a reduced 2-person load-carry team for males and females, respectively. The authors from this study conclude that repeated stretcher carries can induce fatigue altering marksmanship. The authors suggest the use of a four-person stretcher carry team and the use of harnesses to minimize fatigue, increase carrying time and speed and reduce marksmanship inaccuracies.

Tikuisis et al., 2002

The purpose of this study was to identify changes in rifle marksmanship performance when acutely exposed to hot or cold thermal strain. Twelve rifle-trained military reservists (7 males, 5 females, age: mean ± SD = 27.2 ± 4.7 yrs) completed simulated rifle marksmanship tasks while exposed to different environmental conditions. Environmental conditions began with a pre-exposure water immersion to achieve thermal strain and consisted of three separate thermal environments: neutral (N; 22°C room temperature; 33-35°C pre-exposure water immersion), hot (H; 35°C room temperature; 39°C pre-exposure water immersion), and cold (C; 5°C room temperature; 29°C pre-exposure water immersion). During each of the environmental conditions' subjects performed four shooting sessions (two pop-up lane targets, and two scenario shooting engagements) lasting approximately 30-min for a total of 2-hours (sixteen total engagements) using a C-7 rifle on a projected infrared laser-based simulated course firing in a prone-supported shooting position. The lane target drill consisted of subjects firing a single round at 5 conventional pop-up targets that were presented for a duration of 4s at random times and locations set to a distance of 125 m. The scenario target drill was based on a simulated course that required subjects to engage 20 random targets that appeared at various times, locations, and distances on the screen and was instructed to use the minimum number of rounds to hit the targets. Body temperatures, subjective rankings of thermal discomfort, saliva cortisol, and measures of marksmanship (accuracy and precision) were recorded throughout each condition. Results from the study suggest that saliva cortisol levels, core temperature, and corresponding hand temperature were significantly greater in the hot compared to the neutral and cold conditions and were consistent with subjective indices of heat illness. Additionally, there was no difference in marksmanship across the sixteen engagements performed during each condition. Results from the lane target drill indicated that shot mean radius and shooting error was significantly higher during the N condition compared to both the H and C. During the scenario engagement drill, marksmanship scores were 6% higher during H compared to N, and 17% higher in the C compared to N, suggesting marksmanship was poorer during the N condition compared with H and C. The authors conclude that thermal strain within the core body range of 36.4°C to 37.9°C does not negatively affect rifle marksmanship performance, even with individuals who reported significant sensation to hot and cold environments.

<u>Evans et al., 2003</u>

The purpose of this study was to assess the effects of upper extremity muscular fatigue on marksmanship performance using a modified M-16A2 rifle simulating realistic recoil. Twelve soldiers (age: mean ± SD = 24.6 ± 6.2 yrs) were assessed using four measurements of marksmanship (target hits, target misses, late fires, and shot group size) at baseline, immediately after fatiguing condition, and 5, 10, and 15-min post-exercise. The two mechanisms of fatigue involved a modified Bruce protocol using an upper-body arm-crank and performing a Military Operations in Urban Terrain (MOUT) obstacle course consisting of heel lifts, window entry, rope pulls, and sandbag stacking. The rapid-fire test used in the study consisted of the subject standing in an unsupported firing position executing shots on 12 targets at a simulated distance of 75 m for 2 s presentation periods. Results from the study indicated that shooting performance did not differ between exercise conditions at any time point. Additionally, the number of misses increased by 55% immediately following exercise and by 33% at the 5-min mark. Group shot tightness was 71% of pre-exercise values immediately following exercise conditions. The authors concluded that both accuracy and precision decreased significantly following upper body fatiguing exercises but recovered to baseline levels at 10-min for several misses and 5-min when evaluating shot group tightness.

Tikuisis & Keefe, 2007

The purpose of this study was to determine the level of cold strain that would degrade rifle shooting performance (target detection, identification, and engagement). Twelve active-duty male soldiers (age: mean ± SD = 28.1 ± 5.5 yrs) completed a repeated simulated rifle marksmanship task while exposed to two different environmental conditions. Environmental conditions consisted of a thermal-neutral control condition (CNTL; 22°C room temperature) and a cold condition (COLD; 0°C room temperature with 5°C water circulated continuously through a tube suit worn by subjects) for a total of 165-min. The marksmanship test utilized an inert, recoil-enabled, C-7A1 rifle on a projected, infrared laser-based simulated course. There were three 15-min marksmanship tasks with two 1-hour vigilance tasks to simulate sentry duty performed between marksmanship tasks. During each 15-min marksmanship task, subjects were instructed to engage a total of 60 targets displayed at random times, locations (close: 25-100m; medium 100-175 m; and far: 175-250 m), and elevations (ground level or balcony) as quickly as possible. During the 1-hour vigilance sessions, subjects were instructed to observe a mountainous desert terrain that displayed 4 stationary targets and eight moving targets that appeared randomly and for a duration of 10s during each 1-hour session. Targets were randomly displayed at various distances and elevations. Results from the study indicated that core temperature and skin temperature were significantly affected during the 165-min COLD exposure. During the marksmanship tasks, the number of target engagements decreased by 4% during the COLD condition compared to the CNTL condition. Additionally, there was no significant difference in target accuracy between each condition, and target engagement times being similar during each condition and target distance (3.4 s, 4.1 s, and 4.6 s for close, medium, and far targets, respectively). During the vigilance task, there was no difference between target detection ability of stationary or moving targets between CNTL and COLD conditions. The authors concluded that cold strain adversely affected the subject's response to target but does not affect their marksmanship ability during controlled environmental exposure lasting less than 3-hours.

Moore et al., 2014

The purpose of this study was to investigate the independent and combined effects of acute altitude exposure and exercise on rifle marksmanship. Fifteen members of a University Reserve Officers' Training Corps (ROTC) program (13 male, 2 females, age: mean ± SD = 26 ± 1 yrs), who were qualified on the M-4 or M-16 rifle took part in the study protocol. The protocol consisted of five separate testing sessions where subjects performed two marksmanship drills with an incremental exercise test on a treadmill in-between, while exposed to simulated altitudes reflecting 162 (sea-level; SL), 1,015 (1K), 2,146 (2K), 3,962 (3K) and 3,962 (4K) m. The incremental exercise test was performed with subjects carrying a 20 kg (males) and a 10 kg load (females) until volitional exhaustion. The marksmanship test required subjects to use an AR-15 rifle synced with a computerized projection system that displayed four different courses of fire (COF). Each COF had a total of ten torso silhouette targets that were randomly displayed at simulated distances of 15-100 m. Subjects would fire one round at the target, attempting to hit the middle square on the torso target reflecting a maximal score of 10 points (100 points possible for each COF test). Results from the study indicated that marksmanship score was significantly less at 4K altitude compared to all other altitude conditions, with a likely trend for scores at 3K to be lower than those at SL and 1K. Specifically, marksmanship scores declined by 17.2% when comparing 4K to SL condition. Additionally, incremental exercise altered marksmanship scores causing marksmanship trial scores to be significantly lower than baseline scores following all COF trials following exercise. There was a strong positive correlation between marksmanship and SaO_2 (r = 0.84), a strong inverse correlation between marksmanship and ventilation rate (r = -0.72), and a modest inverse correlation between marksmanship and heart rate (r = -0.54). The authors concluded that increasing altitude impairs marksmanship with a threshold around 3,000-4,000 m. Additionally, decreases in marksmanship scores are closely related to decreased arterial oxygen saturation, and increased ventilation indicating the importance of breathing and controlling the movement of the chest wall to minimize marksmanship alterations.

Kryskow et al., 2013

The purpose of this study was to determine the altitude threshold for when simple and complex military task performance is degraded. Fifty-seven active duty low-land residents (age: mean ± SD = 22 ± 3 yrs) were randomized into four altitude conditions: 2,500 m (n = 17), 3,000 m (n = 12), 3,500 m (n = 11), or 4,300 m (n = 17). For each altitude condition, the simple military task consisted of disassembly and reassembly of an M-16 A4 rifle, whereas the complex military task consisted of rifle marksmanship using an inert M4 rifle on a simulated marksmanship course. Each simple and complex military task were evaluated at sea level, 8-hours of exposure and after 30-hours of exposure Results from the study indicated that a simple military task to assess psychomotor performance (disassembly/reassembly of a rifle), was not affected by altitude exposures between 2,500-4,300 m for a period less than 30-hours. Additionally, targets hit per min (during the rifle marksmanship task, displayed a 15% decrease from sea level to 8-hours and 30-hours of exposure only during the 4,300 m condition. However, there were no changes in rifle accuracy between altitude conditions and exposure periods of 8-hours to 30-hours. The authors conclude that psychomotor performance (disassembly/reassembly of a rifle) is not affected by exposures between 2,500-4,300 m but complex psychomotor performance (rifle marksmanship) is degraded at 4,300m within a 30-hour period. Additionally, the authors hypothesize that decrements in rifle marksmanship speed occurred to maintain accuracy during altitude exposure periods between 8 to 30-hours.

Tenan et al., 2017

The purpose of this study was to investigate if soldier rucksack load, marching distance, and average heart rate would affect rifle marksmanship. Twelve male soldiers (age: mean ± SD = 24.6 ± 6.2 yrs) with the previous qualification as a Sharpshooter or Expert with an M4 carbine took part in the study protocol. The protocol began with the subjects completing a cross-country ruck march for a total distance of 11.8 km at a pace of 4.3km/hour while either carrying a rucksack load of 48.5 kg or a rifle man load of 26.1 kg evenly distributed throughout the pack. Upon reaching the shooting range, the soldiers would remove their rucksack, if being carried, and immediately perform the shooting task using an M4 carbine rifle. The shooting task consisted of targets placed at 100 and 150 m. A total of 48 targets were exposed individually for 8 s with a presentation period separated by 2.5 seconds. Soldiers were instructed to assume either a standing kneeling, or prone posture, and engage the target by firing a single round trying to be as accurate as possible to the 2x2 inch square placed in the center of the target. Heart rate was measured throughout the loaded ruck march and shooting drill, while marksmanship after the loaded ruck march was compared to pre-test marksmanship scores. Results from the study indicated that the effects of load carried, and average shooting heart rate affected marksmanship in a nonlinear manor when assessed by target hit and misses. Additionally, pre-march marksmanship was increased by an average of 15% in the rucksack condition compared to the pre-march marksmanship in the rifleman load carry condition. Assessing heart rate, load carried together during marksmanship, suggested that both variables (hear rate and load carried) altered marksmanship performance non-linearly. However, in both conditions, marching led to an increase in marksmanship. The authors concluded that marksmanship improvements during the pre-march task were attributed to more of a psychological effect increasing the shooter's arousal rather than physiological effect (heart rate and fatigue due to load carried). Additionally, the authors suggest that rucksack load and marching may not uniformly decrease changes in marksmanship performance.

Chapter 3: Methodology

3.1 Experimental Approach

A within-subjects, repeated-measure design was used to investigate independent effects of cold and combined cold and hypoxia exposure on pistol shooting performance measured before and after a fatiguing exercise protocol. Environmental conditions consisted of two different temperatures (10°C and 24°C) and two different simulated altitudes (1,067 m [F_IO_2 = 21%] and 3,048 m [F_IO_2 = 14.3%]). The Baseline conditions were performed at 24°C and a simulated altitude of 1,067 [F_IO_2 = 21%]. The cold normoxic (C-NORM) condition was performed at 10°C and a simulated altitude of 1,067 m [F_IO_2 = 21%]. Lastly, the cold hypoxic (C-HIGH) condition was performed at 10°C and a simulated altitude of 3,048 m [F_IO_2 = 14.3%].

The sequence of each condition began with an initial exposure period, during which subjects sat at rest while vital signs were monitored every 10-min for a 30-min period. Following the initial exposure period, subjects transitioned to the testing protocol, where pistol shooting performance was measured twice, once before a fatiguing dynamic exercise, and again immediately following the fatiguing dynamic exercise. Pistol shooting performance was measured by utilizing three different shooting scenarios. The shooting scenarios consisted of a marksmanship course (Marine Pistol Qualification), a shoot-no-shoot course (Match Target Drill), and a speed reaction course (Speed Drill). The fatiguing exercise protocol consisted of the subjects' performing three sets of sandbag deadlifts at 50% body weight until volitional exhaustion. In addition, following each set of the sandbag deadlifts, each subject performed a maximal isometric voluntary contraction (MVIC) using a mid-thigh pull device. Throughout each environmental exposure condition and the sandbag deadlift repetitions to failure, total saturation index (%TSI) was recorded from the vastus lateralis (VL) muscle to identify changes in muscle oxygenation throughout environmental exposure and during the fatiguing exercise protocol. In addition, maximal isometric strength using the mid-thigh pull device and skin temperatures of the fingers and hands using a thermal camera was assessed at various timepoints throughout the protocol (Figure 1). At the end of the protocol, subjects transitioned to a recovery period where they were seated for a duration of 10-min. Throughout the 10-min recovery period, the subjects' vital signs were monitored twice separated by 10-min.

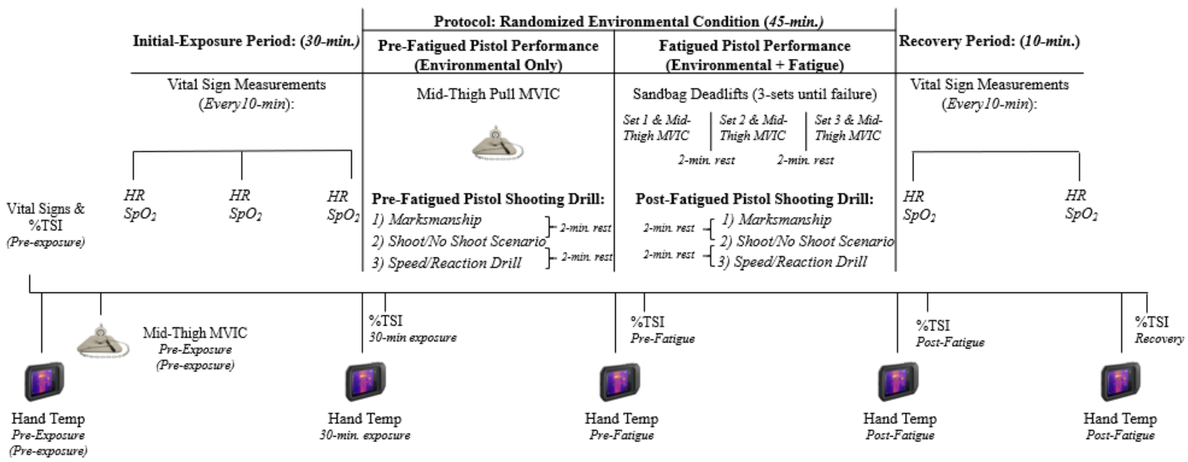

Figure 1. *Outline of the study protocol for each visit. Visits are broken down into three sections (initial exposure, protocol, and recovery). In addition, specific time points are indicated for when vital sign recordings, infrared thermography, and %TSI are being measured.*

3.2 Subjects

Six subjects (4 males, 2 females; age: mean ± SD = 28.5±2.93 yrs) in possession of a marksmanship badge or license to carry permit participated in this study. A power analysis was conducted utilizing the data from Brown et al., 2013 to determine that a sample size of 6 is required to reach 0.95 power (G*Power 3.1) (Figure 2). All subjects signed written informed consent, completed a health history questionnaire, and provided proof of qualification that they have previously received pistol marksmanship training.

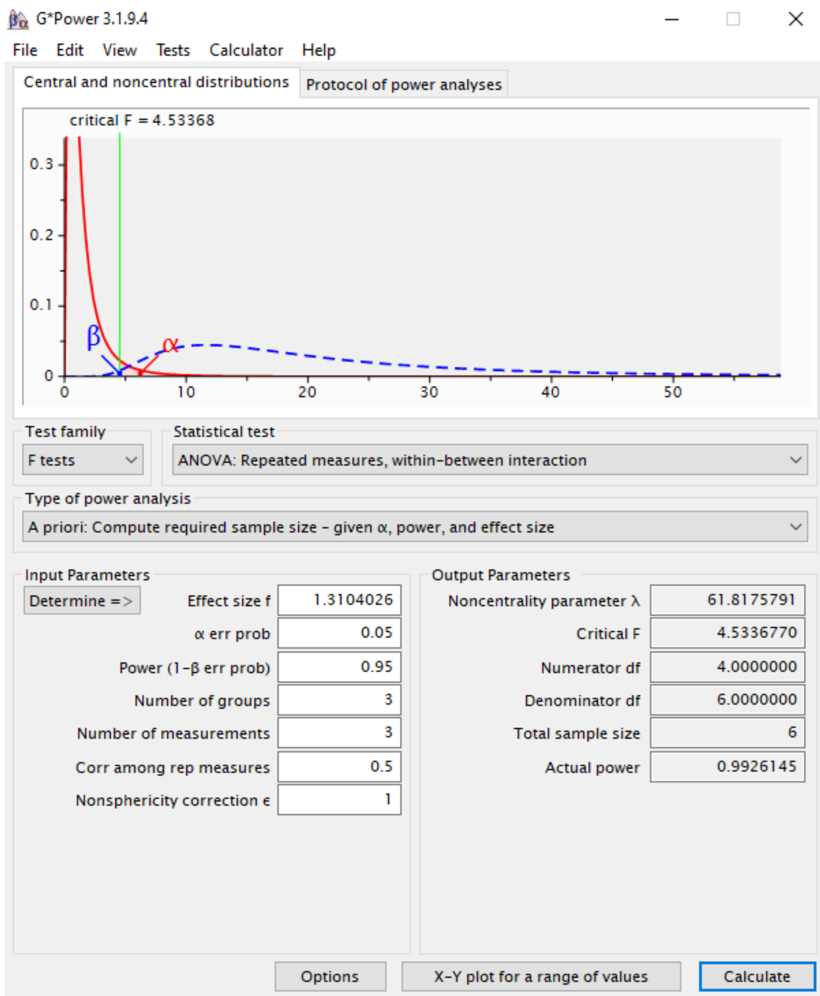

Figure 2. *Power analysis performed by G*Power 3.1 to reach a power of 0.95 with an effect size of 1.31.*

3.3 Protocol

Each subject reported to the laboratory for a total of four visits. The first visit served as a familiarization session where subjects were introduced to the equipment and instructed how to perform the sandbag deadlift and isometric mid-thigh pull. In addition, subjects were introduced to the environmental room where they were familiarized with the electronic marksmanship simulator by firing 5 shots at target distances corresponding to simulated distances of 5, 10, 20, and 25 yards, for a total of 20 rounds. This allowed subjects to feel the recoil of the pistol and experience how targets will be presented on the projector screen throughout each pistol shooting scenario. Following the practice round, subjects performed one practice trial for each of the three simulation shooting scenarios that were tested. The protocol for visits 2 – 4 followed the same format as outlined in Figure 1., however, subject exposure to environmental conditions was manipulated for each subsequential visit. The order of environmental conditions was randomized for each subject. The Baseline condition consisted of an ambient temperature of 24°C and a simulated altitude of 1,067 m (F_IO_2 = 21%). This environmental condition is intended to be identical to the relative temperature and altitude conditions of El Paso, TX in the Fall months (September – November). A cold temperature condition (C-NORM) consisted of an ambient temperature of 10°C and the same simulated altitude as the Baseline condition (1,067 m [F_IO_2 = 21%]). This environmental condition is intended to simulate a rapid exposure to nighttime conditions of an arid desert climate, or common daytime climactic patterns of Winter months (October – April) within lowland Middle Eastern desert conditions. Lastly, a cold temperature, high altitude condition (C-HIGH) consisting of an ambient temperature of 10°C and a simulated altitude of 3,048 m (F_IO_2 = 14.3%) was tested. The C-HIGH condition attempted to simulate a rapid ascent to conditions mimicking daytime and nighttime climactic patterns of Winter months (October – April) in the Middle Eastern desert, or when venturing into mountainous terrain commonly found within the Hindu-Kush region (Figure 3).

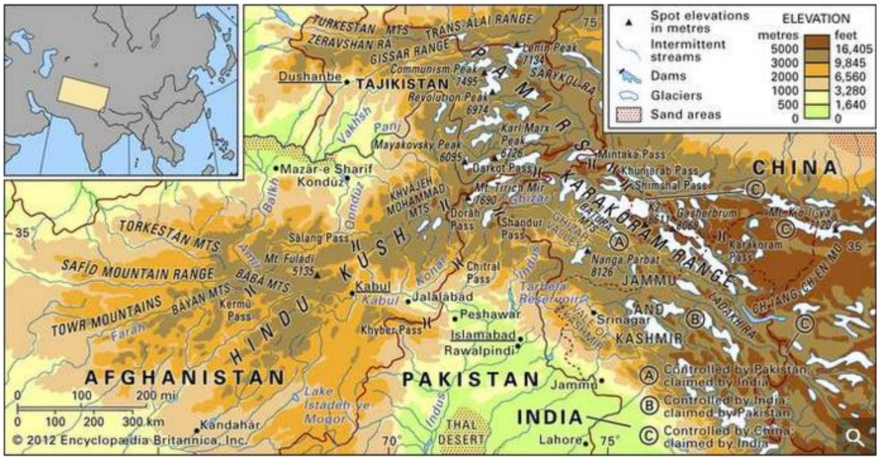

Figure 3. *Topographic map of the Hindu-Kush mountain range located to the northeast of Afghanistan.*

Each laboratory visit was divided into three parts: initial-exposure period, protocol, and recovery period. Before the initial exposure period, a pre-exposure thermal image of the right and left hand was assessed, and pre-exposure vital signs recordings (heart rate, oxygen saturation,) were obtained. Following the vital signs measurement and thermal imaging, a voluntary maximal voluntary isometric contraction (MVIC) on the mid-thigh pull device will be performed (Figure 6). Once all pre-exposure assessments were completed, subjects were then introduced to the environmental room set to the specific thermal condition. To simulate normobaric hypoxia, subjects were hooked up to an Oro-Nasal facemask which was connected to an altitude generator (HYP 123 Generator, Hypoxico Altitude Training Systems, New York, NY, USA). The hose that connects the facemask to the generator was separated by a 4L Douglas bag and a 120L Douglas bag, to allow free-flowing hypoxic air for the subjects to breathe without the restriction of a tube. Additionally, an oxygen monitoring device (MySign®O; EnviteC by Honeywell, Wismar, Germany) was used to monitor oxygen concentration delivered from the altitude generator during each environmental condition. During the pre-exposure period, subjects were seated in an upright position in the environmental room for a duration of 30-min. While seated, heart rate (HR), and peripheral oxygen saturation (SpO_2), were recorded at 10-min intervals throughout the 30-min exposure period for a total of 3 timepoints.

The protocol section consists of pistol shooting performance assessments and a muscular fatiguing protocol. To evaluate the independent effects of the environmental condition on maximal isometric strength and pistol shooting performance, the subjects began by performing an MVIC on the mid-thigh pull device. Following the mid-thigh pull subjects transitioned to the shooting drill where they performed the Marine Pistol Qualification Course to evaluate marksmanship, a Match Target drill that assessed shoot/no-shoot task performance, and a Speed Drill that examined reaction time and accuracy. Each pistol shooting drill was separated by a 2-min rest period and was performed in the same order that is currently listed. Following the completion of the Speed Drill, subjects then transitioned to the fatiguing sandbag deadlift exercise portion of the protocol. Subjects completed a total of 3 sets of sandbag deadlifts performing as many repetitions as possible until volitional exhaustion, or failure to maintain proper form for two consecutive repetitions. Immediately after each of the three sets of the sandbag deadlifts, each subject performed a 6-s MVIC on the mid-thigh pull device. A 2-min rest period was provided between each set to allow time to complete the 6-s MVIC. Following the third and final set of the sandbag deadlifts and 6-s MVIC on the mid-thigh pull device, the subject immediately transitioned to the pistol shooting drill without the 2-min rest period. Each subject then completes the same 3 shooting tasks as outlined previously in the same order listed.

The recovery period was similar to the pre-exposure period; however, subjects were seated in an upright position where HR and SpO_2 were monitored twice throughout the 10-min recovery period. After the recovery period, subjects were allowed to remove the Oro-nasal facemask, stand up, and exit the environmental room.

3.4 Vital Sign Acquisition

Vital Sign measurements, HR, and SpO_2 were assessed at various timepoints throughout each visit using an automated patient monitoring device (Hewlett-Packard Agilent Phillips Viridia V24C). Heart rate and peripheral oxygen saturation were monitored using a Phillips reusable pulse oximeter sensor connected to the patient monitoring device.

3.5 Thermal Imagery

Infrared imaging using a FLIR C2 thermal imaging camera (FLIR Systems Ltd, Wilsonville, OR) was used to assess mean temperature changes within the skin surface temperature of the fingers at three different anatomical locations: the distal interphalangeal (DIP) joint, the proximal interphalangeal (PIP) joint, and the metacarpophalangeal (MCP) joint on the dorsal side of the right and left hand in accordance with the methods outlined by Zaltar et al., 2015. Additionally, skin temperature of the dorsal hand segment was used to measure changes in hand temperature between the radiocarpal joint and the MCP joint of the 2nd through 5th digit of the right and left hand (Figure 4.)

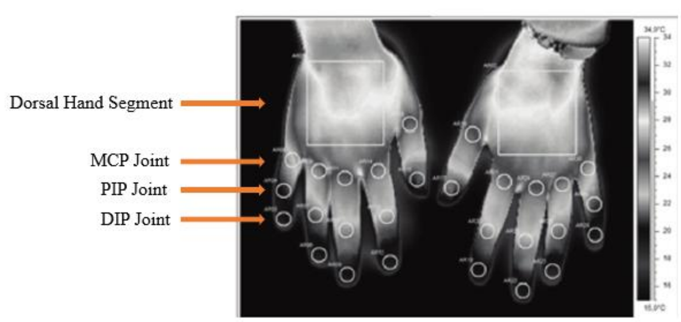

Figure 4. *Thermal measurement sites used to measure changes in finger skin temperatures: DIP, PIP, and MCJ joints (circles) and the skin temperature changes of the dorsal hand segment (box).*

Changes in finger skin temperature were calculated from circular spot measurement markers located at three anatomical joints (DIP, PIP, and MCP) for all five digits of the right and left hand. Finger skin temperatures were averaged across each joint location for all five digits of each hand. Additionally, dorsal hand segment skin temperatures were calculated from a box measurement placed at the specific anatomical sites for both the right and left hand (Figure 4.) Skin temperatures for the fingers and the hand were measured at 5 specific timepoints across each visit: before exposure (pre-exposure), after 30-min of environmental exposure (30-min exposure), before fatiguing pistol performance protocol (pre-fatigue), following the fatiguing pistol performance protocol (post-fatigue), and after 10-min of recovery (recovery) (Figure 1). Each thermal image was taken with the camera at a 90° angle directly over the subjects' right and left hands placed palmar side down on a medium-density fiberboard with fingers spread equally apart (Jones et al., 2018). Prior to thermal imaging, the camera was calibrated in accordance with the manufacture's guidelines with emissivity (Ɛ) set to 0.95, reflected temperature set to 24°C, and distance from hands set to 0.50 m. The mean finger and hand skin temperatures of the specific anatomic locations were segmented and analyzed offline using FLIR Tools application (Version 5.13, FLIR Systems Ltd, Wilsonville, OR). Finger and hand skin temperatures were measured across each timepoint and across each environmental condition.

3.6 Near-Infrared Spectroscopy (NIRS)

Muscle oxygenation of the right vastus lateralis (VL) was monitored continuously throughout the visit by using a near-infrared spectroscopy (NIRS) device (Oxymon M III, Atrinis Medical System, BV, Netherlands). Determination of tissue oxygenation using NIRS is based on the Beer-Lambert Law, which quantifies the reduction in light traveling through a non-scattering medium. This law is mathematically expressed within biological tissue as $OD_\lambda = \log(Io/I) = \varepsilon_\lambda \, c \cdot L_O \cdot DPF + OD_{\lambda x}$, where OD_λ is the medium's optical density, I_O is the incident light intensity, I is the transmitted light intensity, ε_λ is the extinction coefficient of the chromophore ($mM^{-1} \cdot cm^{-1}$), c is the concentration of the chromophore (mM^{-1}), L_O is the distance (cm) between light entry and exit, and λ is the wavelength of light used (Deply et al., 1988). Within biological tissue, near-infrared light is absorbed by heme groups within hemoglobin (Hb) and myoglobin (Mb); thus, NIRS cannot differentiate between the two species (Subduhi et al., 2007). The ability of NIRS to quantify changes in oxygenation is based on differences within the absorption spectra for oxygenated and de-oxygenated heme groups. Near-Infrared Spectroscopy records the absorbance of light at several wavelengths where changes in the absorbance spectrum near 850 nm is associated with oxygenated hemoglobin/ myoglobin, and absorbance within the 760 nm is associated with de-oxygenated hemoglobin/myoglobin (Sanni & McCully, 2019). Tissue saturation index (%TSI) provides information on changes within the absorbance spectra (ratio of oxygenated and de-oxygenated heme groups) and can be expressed mathematically as 850/(850 + 760) nm ·100 to produce percentage values (Jones & Cooper, 2018). Therefore, NIRS measurement, %TSI, can provide an index for overall tissue oxygenation.

For each visit, the NIRS device was placed on the muscle belly of the VL approximately 66% of the distance between the anterior superior iliac spine (ASIS) and lateral epicondyle of the femur. The skin was shaven, abraded, and cleaned with isopropyl alcohol prior to placement. The NIRS device was secured to the VL using double-sided Velcro straps wrapped around the subject's right thigh. An elastic bandage (3M Corporation, St. Paul, MN) was used to secure the device in place during dynamic movements and help prevent contamination from ambient light. Figure 5 depicts the optode template arrangement for the NIRS device (Figure 5). Data were sampled at 10 Hz (Subdhui et al., 2007; Scott et al., 2018; Sanni & McCully, 2019) and transferred to a personal computer using Oxysoft software (Oxysoft, Artinis Medical Systems, BV, Netherlands). Prior to all recording, NIRS values were zero calibrated in a resting state prior to the start of the protocol.

Tissue saturation index (%TSI) was examined throughout the concentric phase during each of the sandbag deadlift repetitions to volitional exhaustion. Repetitions were normalized for every 10% of the total repetitions completed (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100% of the repetitions to failure) and if the percent to failure was between repetitions, the repetition immediately following was selected (i.e., if 10% of the repetitions to failure is at repetition 7.5, repetition eight was used as the 10% of the repetitions to failure). Changes in %TSI were calculated by normalizing values to the initial rep performed during the Baseline condition in order to observe changes in %TSI throughout each set during each condition.

The change in %TSI throughout condition was calculated by taking the mean of 10-s epoch segment throughout specific timepoints during the protocol in accordance with the methodology presented by Murray et al., 2020. The corresponding timepoints where the 10-s %TSI epochs were recorded were: 10-s before pre-exposure vital signs measurement (pre-exposure), 10-s before last vital signs time point during 30-min initial exposure period (30-min exposure), 10-s immediately after pre-fatigued (Pre-fatigued), 10-s after post-fatigue (post-fatigued) pistol shooting scenarios, and 10-s before the final vital signs measurement during the recovery period (Recovery) for a total of 5 separate timepoints. To measure the time course of changes throughout each visit, the %TSI epochs were normalized to the initial %TSI epoch (Pre-exposure) obtained during the Baseline condition. All %TSI, measurements were selected off-line using custom-written LabVIEW programs (Version 19.0, National Instruments, Austin, TX).

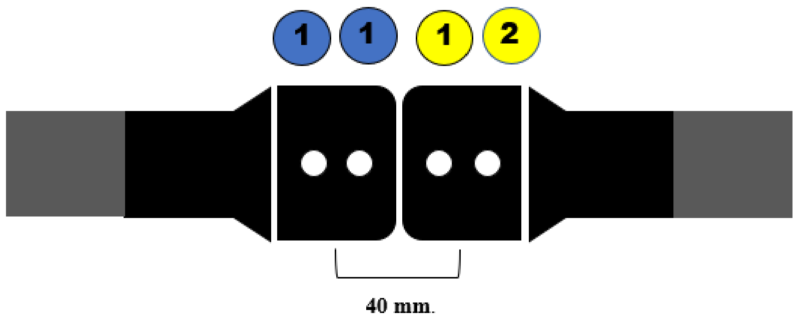

Figure 5. *Example of NIRS optode arrangement placed on the VL. Transmitter (Blue) and receiver (yellow) with an inter-optode distance of 45 mm.*

3.7 Isometric Mid-Thigh Pull

The maximal isometric mid-thigh pull contractions were performed using a BASELINE® Hydraulic push-pull dynamometer (Fabrication Enterprises, Inc. White Plains, NY). Following all pre-exposure measurements (vital signs, hand temperature, and %TSI) subject performed a brief warm-up on the mid-thigh pull device. Subjects were instructed to pull at approximately 50-80% of their perceived maximal voluntary isometric contraction (MVIC) force for 3 – 5 repetitions (Figure 6). Following the warm-up, each subject performed two, 6-s MVIC mid-thigh pulls to establish a pre-exposure maximal force value. After 30-min of environmental exposure, subjects performed an additional single 6-s MVIC mid-thigh pull. During the exercise fatigue portion of the protocol, each subject performed a 6-s MVIC mid-thigh pull immediately following each set of the fatiguing sandbag deadlifts. For each isometric mid-thigh pull contraction, the subjects set up to the bar where; feet were hip-width apart, the bar positioned midway between the knees and hips, and knee and hip angles flexed between 140 ± 5° and 135 ± 5°, respectively (Haff et al., 2015; Moeskops et al., 2018; De Witt et al., 2018). A Standard BASELINE® 12-inch plastic goniometer (Fabrication Enterprises, Inc. White Plains, NY) was used to verify joint angles prior to the subject performing lift. Peak force values (N) were calculated from each 6-s MVIC mid-thigh pull, normalized to subjects' body mass (kg), and were expressed as relative peak force (N/Kg). Relative force values were compared across environmental conditions and throughout each set completed throughout the visit.

Figure 6. *Hydraulic push-pull dynamometer used for the isometric mid-thigh pull.*

3.8 Sandbag Deadlift Protocol

The sandbag deadlift protocol was performed using a large training sandbag (Weight Training Sandbag Titan Fitness, Mc Lean, VA). The load selected for the sandbags was equivalent to 50% of the subject's body mass calculated from anthropometric data collected during the familiarization visit. The utilization of sandbag training was based on the recommendations from Haddock et al., 2016, the Militaries Occupational Physical Assessment (OPAT), and the newly developed Army Combat Fitness Test (ACFT) (USARIEM Technical Report T16-2, 2015; U.S. Army Field Testing Manual, V 1.4 – 20180827, 2019). Specifically, Haddock et al., 2016 reported that sandbag training was a high-intensity functional training methodology that was designed for use in operational environments and mimics combat-oriented tasks. Further, sandbag resistance at 50% body mass allows for the load to mimic those suggested and measured during the OPAT and ACFT (USARIEM Technical Report T16-2, 2015; U.S. Army Field Testing Manual, V 1.4 – 20180827, 2019). To achieve the 50% body mass, smaller custom weight sandbags were arranged in a larger sealed sandbag until the total required load was obtained. Subjects were instructed to perform the sandbag deadlift exercise by keeping a neutral spine, and flex at the hips, knees, and ankles to grab the sandbag handles with a pronated grip. A full repetition required the subject to extend at the hips and knees raising the sandbag to a position just above the knees with the shoulders over the bag and hips fully extended in accordance with the National Strength and Conditioning Association's (NSCAs) guidelines (Baechle & Earle, 2008). Upon reaching the upright position, subjects were allowed to release the sandbag allowing the sandbag to drop to the floor, and resume deadlift repetitions following the same form as outlined previously. Subjects completed a total of 3 sets of sandbag deadlifts performing as many repetitions as possible until volitional exhaustion, or failure to maintain proper form for two consecutive repetitions. Each subject received strong verbal encouragement throughout the sandbag deadlift protocol.

3.9 Pistol Shooting Performance

An inert recoil-enabled Glock 17 pistol (Laser Ammo Ltd., Great Neck, NY), equipped with a custom Umarex drop-in barrel with an infrared SureStrike™ vibration activated laser attached to the muzzle was used throughout the pistol shooting performance scenarios. The Glock 17 used within the study protocol mimicked the size, weight, and performance specifications of a fully operational Glock 17. In addition, the magazine that was used with Glock 17 contained a hollow chamber with a fuel fill inlet on the bottom, to allow pressurized green gas (Elite Force Airsoft, Fort Smith, AR) to be loaded into the magazine to simulate recoil

A Smokeless Range 2.0 ® Judgmental and Marksmanship Shooting Simulator (Laser Ammo Ltd. Le Zion, Israel), was set up in the 2.4 X 3.0 m environmental room and was used to assess pistol shooting performance. The three shooting scenarios used throughout the study consisted of Marine Pistol Qualification Course, Match Target Drill, and Speed Drill. Subjects performed each of the 3 pistol shooting performance scenarios in the standing position, starting with the pistol secured in a holster at the subject's self-selected hip location. For each shooting scenario, the subject was facing a 60 in x 40 in projector screen, standing 2 yards away, where a high-resolution ViewSonic Home theater PA503S DLP Projector (ViewSonic Inc. Brea, CA) displayed the different courses for each shooting scenario, and a short-throw camera (Laser Ammo Ltd. Le Zion, Israel), was used to track target hits, misses and the total number of shots fired.

The Marine Pistol Qualification Course is designed to test individuals' marksmanship at distances varying from 7 yards to 25 yards (Figure 7). This scenario was performed with the subject in the standing position. The target used in this drill simulates a life-sized man with various point regions for specific locations on the body (Figure 7). The shooting drill began with stage 1 which consists of three different target interactions while presented at a simulated distance of 7 yards. Throughout stage 1, subjects were instructed to fire a total of 16 rounds at specified locations consisting of center mass and the head, attempting to hit the center of the target to accrue the most points possible (Figure 7). During stage 2, target interactions were presented at a simulated distance of 15 yards. Throughout the 2nd stage, subjects fired a total of 16 rounds attempting to hit the center mass of the target. Stage 3 consists of one target interaction presented at a simulated distance of 25 yards. Throughout the 3rd stage, the subject was instructed to aim and fire a total of 8 rounds at the target attempting to hit as close to center mass as possible. The goal for this shooting scenario was to simulate a combat pistol course mimicking tower operation commands to engage targets at specific distances. In total, The

Marine Pistol Qualification Course consisted of 40 rounds. (Figure 8). Marksmanship scores were calculated based on the locations of the hits on the target in relation to the center mass. Scoring was calculated using an official U.S. Marines Pistol Program scorecard (Appendix A) and was compared throughout the visit and across each environmental condition.

The Match Target Drill is designed to test the subject's rapid decision-making skills through a simulated shoot/no-shoot scenario. This scenario began with the subject in the standing position. Target projections were displayed at a simulated distance of 10 yards throughout the entire scenario. The targets consisted of carious numbers with specific color patterns appearing on the screen with audible commands instructing subjects to aim and fire at specific targets (Figure 8). Once each of the appropriate targets is hit, the screen advanced to a new round displaying a new set of colored numbers placed in randomized target positions. The goal for this shooting scenario was to be quick and accurate to quickly engage and clear appropriate colored targets for 5 consecutive stages. The number of misses was recorded and assessed throughout the visit and across each environmental condition.

The Speed Drill scenario is designed to assess reactive pistol shooting speed and accuracy. Each subject started in the standing position with the pistol in a holster on the subject's self-selected hip. A steel plate target with a light in the middle of the target was displayed at a simulated distance of 5 yards (Figure 9). Subjects were instructed to stand with their hands at their sides while the pistol was in the holster with no portion of the hand placed on the pistol. Subjects remained in this position until the light in the middle of the steel target illuminated indicating that the subjects could reach for the pistol, draw and shoot. The goal for this shooting scenario is to simulate a close-quarters threat, challenging the subject to rapidly unholster the pistol, aim, and accurately discharge the pistol at the targe as fast as possible. Any hit on the steel target caused a stoppage on the automatic timer. The Speed Drill was repeated two more times for a total of three reaction times. The three reaction times were averaged and compared throughout the visit and across each environmental condition. A modified version of the rules adapted from the World Fast Draw Association was used to instruct subjects on how to perform the Speed Drill (Appendix B).

Iterations	Total Rounds	Time	Mode	Fill Plan
Stage One – 7 yards				
2 (3 times)	6	5 sec	Controlled Pair from Holster	Load 14 in weapon; 9 in pouch Analyze & repair
2 } 1 } (2 times)	6	7 sec	Failure to Stop from Holster	8 in weapon; 9 in pouch Analyze & repair
2 } 2 }	4	9 sec	Speed Reload from Holster	2 in weapon; 9 in pouch Fill mag w/7 Analyze & repair
Stage Two – 15 yards				
2 (6 times)	12	6 sec	Controlled Pair from Holster	7 in weapon; 7 in pouch After 3rd drill, Tactical Reload w/ mag 7 Fill mag w/10 Analyze & repair
2 } 2 }	4	12 sec	Speed Reload from Holster	2 in weapon; 10 in pouch Analyze & repair
Stage Three – 25 yards				
1 (8 times)	8	7 sec	Single Action Slow Fire (Threat Assessment) from Tactical Carry	8 in weapon Analyze & repair
Total rounds = 40				

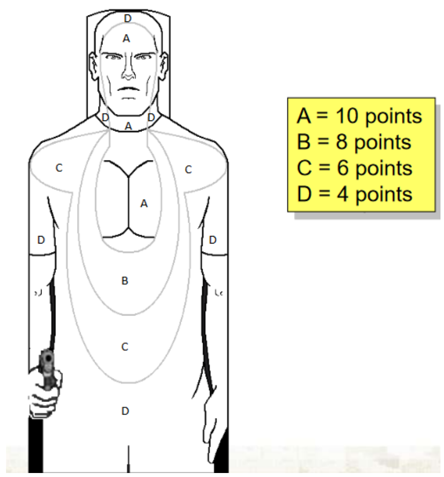

Figure 7. *Example of stages for Marine Pistol Qualification course with target and point distribution.*

Figure 8. *Example of Match Target Drill with a specific audible command*

Figure 9. *Example of Speed Drill Target.*

3.13 Statistical Analyses

3.13a Vital Signs

Two separate, 3 (Condition: Baseline, C-NORM, and C-HIGH) x 6 (Vital signs time points: pre-exposure, 10-min exposure, 20-min exposure, 30-min exposure, 0-min recovery, and 10-min recovery) two-way repeated measure ANOVAs were performed to examine the time course of changes in HR and SpO_2 throughout each visit. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

3.13b Thermal Imagery

A single, 3 (Condition: Baseline, C-NORM, and C-HIGH) x 4 (Thermal timepoints: Pre-exposure, 30 min exposure, Pre-fatigue, and Post-fatigue) x 2 (Finger skin temperature: left and right) three-way repeated measure ANOVAs were performed to examine the time course of change in mean finger skin temperatures throughout the duration of the visit. If there was no significant difference between visits, (Baseline, C-NORM, and C-HIGH) changes in hand temperatures were then collapsed across visits. In a scenario where there was a significant difference between visits, or if collapsed across visits, an appropriate 5 (Thermal timepoints: Pre-exposures, 30-min exposure, Pre-fatigue, Post-fatigue, and Recovery) x 2 (Dorsal finger skin temperature: left and right) two-way repeated-measures ANOVA was performed. Follow-up one-way repeated measure ANOVAs, as well as post-hoc paired sample t-tests with Tukey-LSD, were used when appropriate.

A single, 3 (Condition: Baseline, C-NORM, and C-HIGH) x 5 (Thermal timepoints: Pre-exposure, 30-min exposure, Pre-fatigue, Post-fatigue, and Recovery) x 2 (Dorsal hand segment skin temperature: left and right) three-way repeated measure ANOVA was performed to examine the time course of change in mean hand segment skin temperatures throughout the duration of the visit. If there was no significant difference between visits, (Baseline, C-NORM, and C-HIGH) changes in hand segment skin temperatures were then collapsed across visits. In a scenario where there was a significant difference between visits, or if collapsed across visits, an appropriate 5 (Thermal timepoints: Baseline, 30 min exposure, Pre-fatigue, Post-fatigue, and recovery) x 2 (Dorsal hand segment skin temperature: left and right) two-way repeated-measures

ANOVA was performed. Follow-up one-way repeated measure ANOVAs, as well as post-hoc paired sample t-tests with Tukey-LSD, were used when appropriate.

3.13c Near-Infrared Spectroscopy (%TSI)

A single, 3 (Condition: Baseline, C-NORM, and C-HIGH) x 3 (Sets: Set #1, Set #2, and Set #3) x 11 (Repetition: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100% of the repetitions to failure) three-way repeated measure ANOVA was performed to examine the time course of changes in %TSI within the VL during repeated sandbag deadlifts. If there was no significant difference between visits (Baseline, C-NORM, and C-HIGH), changes in %TSI were then collapsed across visits. In a scenario where there was a significant difference between visits, or if collapsed across visits, an appropriate 3 (Sets: Set #1, Set #2, and Set #3) x 11 (Repetition: 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100% of the repetitions to failure) two-way repeated-measures ANOVA was performed. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

A single 3 (Condition: Baseline, C-NORM, and C-HIGH) x 5 (%TSI epoch timepoint: Pre-exposure, 30-min exposure, Pre-fatigue, Post-fatigue, and Recovery) two-way repeated measure ANOVA was performed to examine the time course of changes in %TSI within the VL throughout each visit. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

3.13d Isometric Mid-Thigh Pull

A single, 3 (Condition: Baseline, C-NORM, and C-HIGH) x 6 (MVIC timepoints: pre-exposure, 30-min exposure, Pre-fatigue, Post-set #1, Post set #2, and Post-set #3) two-way repeated-measures ANOVA was performed to examine the time course of changes in relative force values throughout each visit. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

3.13e Sandbag Deadlifts

A single, 3 (Condition: Baseline, C-NORM, and C-HIGH) by 3 (Repetitions: set #1, set #2, and set #3) repeated measure ANOVA was performed to examine changes between the number of sandbag deadlift repetitions performed across each of the three sets and throughout the three different conditions. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

3.13f Pistol Shooting Performance

A single 3 (Condition: Baseline, C-NORM, and C-HIGH) x 2 (Shooting conditions: Pre-fatigued and Post-fatigued) two-way repeated measure ANOVA was performed to examine changes in marksmanship scores time during The Marine Pistol Qualification Course. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

A single 3 (Condition: Baseline, C-NORM, and C-HIGH) x 2 (Shooting conditions: Pre-fatigued and Post-fatigued) two-way repeated measure ANOVA was performed to examine changes in the number of misses that occurred during the Match Target Drill. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

A single 3 (Condition: Baseline, C-NORM, and C-HIGH) x 2 (Shooting conditions: Pre-fatigued and Post-fatigued) two-way repeated measure ANOVA was performed to examine changes in reaction time during the Speed Drill. Follow-up one-way repeated measure ANOVAs, as well as post-hoc, paired sampled t-tests with Tukey-LSD were used when appropriate.

For all ANOVA analyses, under conditions where sphericity was violated, the Greenhouse-Geisser correction factor was used. Effect sizes were reported for all significant interactions and main effects using partial eta squared calculation. All analyses were conducted using SPSS (IBM SPSS Inc., Chicago, IL, USA). An alpha level $p \leq 0.05$ was considered statistically significant for all comparisons.

Chapter 4: Results

4.1 Vital Signs

The 3 (Condition: Baseline, C-NORM, and C-HIGH) by 6 (Timepoint: pre-exposure, 10-min exposure, 20-min exposure, 30-min exposure, 0-min recovery, 10-min recovery) repeated measure ANOVA indicated no significant two-way interaction for Condition x Timepoint (p = 0.07; η_p^2= 0.28) or main effect for Condition (p = 0.81; η_p^2= 0.04). There was, however, a significant main effect for Timepoint (p < 0.001; η_p^2= 0.78) indicating HR at 0-min recovery > pre-exposure and 20-min exposure timepoints (p = 0.03 – 0.04), and 10-min recovery > pre-exposure, 10-min exposure, 20-min exposure, and 30-min exposure timepoints (p = 0.01 – 0.05) (Figure 10).

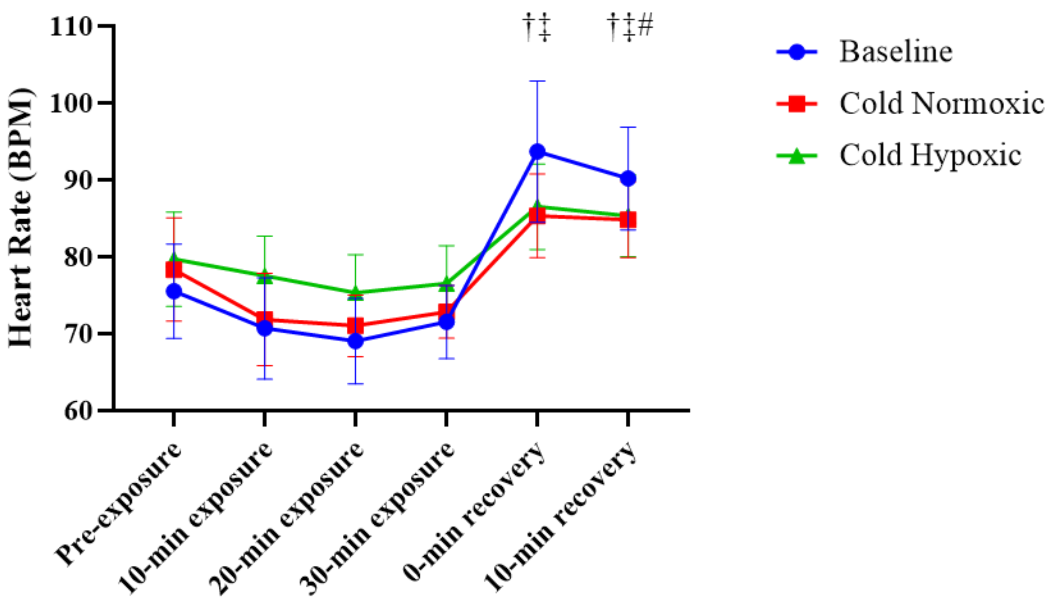

Figure 10. *Heart rate values observed across environmental exposure timepoints (Mean ± SEM). † indicates timepoint is > pre-exposure timepoint (p < 0.05). ‡ indicates timepoint >than 20-min exposure timepoint (p < 0.05). # indicates timepoint is > than 30-min exposure timepoint (p < 0.05).*

For SpO_2 the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 6 (Timepoint: Pre-exposure, 10-min exposure, 20-min exposure, 30-min exposure, 0-min recovery, 10-min recovery) repeated measure ANOVA indicated a significant two-way interaction for Condition x Timepoint (p = 0.004; η_p^2= 0.64). Three follow-up one-way repeated measure ANOVA was performed to assess changes in SpO_2 across timepoints for each of the three conditions. Results indicated that there was no significant difference in SpO_2 values across each timepoint throughout the Baseline condition ($p = 0.10$; $\eta_p^2 = 0.29$). Additionally, there was no significant difference in SpO_2 values across each timepoint throughout the C-NORM condition ($p = 0.47$; $\eta_p^2 = 0.15$). However, there was a significant difference in SpO_2 values across each timepoint throughout the C-HIGH condition ($p = 0.006$; $\eta_p^2 = 0.69$) indicating pre-exposure SpO_2 values > 10-min exposure, 30-min exposure, 0-min recovery and 10-min recovery SpO_2 values (p = 0.03 – 0.05). In addition, six follow-up one-way repeated measure ANOVA was performed for each timepoint across each of the three conditions. Results indicated that there was no significant difference in SpO_2 values during the pre-exposure timepoint across each of the three conditions ($p = 0.65$; $\eta_p^2 = 0.06$). However, there was a significant difference in SpO_2 values during the 10-min exposure, 20-min exposure, 30-min exposure, 0-min recovery, and 10-min recovery across each of the three conditions (p = >0.001 – 0.02; η_p^2 = 0.72 – 0.89) indicating Baseline > C-HIGH (p = 0.01 – 0.04) and C-NORM > C-HIGH (p = 0.01 – 0.02) (Figure 11).

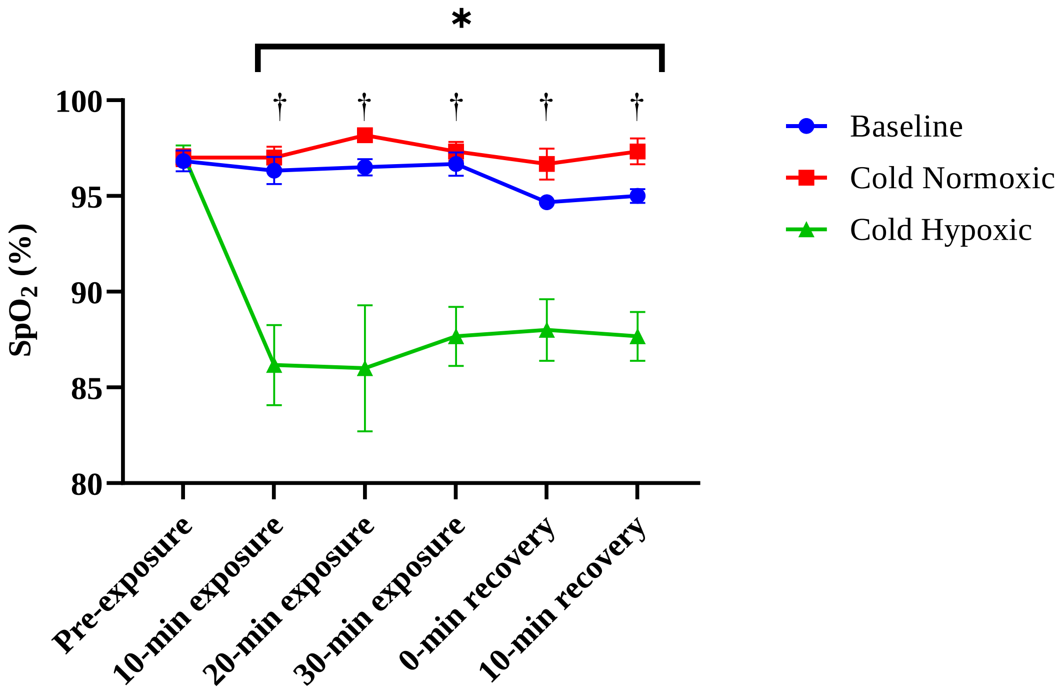

Figure 11. *SpO_2 values observed across environmental exposure timepoints (Mean ± SEM). * indicates C-HIGH < Baseline and C-NORM ($p < 0.05$). † indicates C-HIGH < Baseline and C-NORM at specific timepoints ($p < 0.05$).*

4.2 Infrared Thermography

For dorsal hand skin temperature, the 3 (Conditions: Baseline, C-NORM, and C-HIGH) by 5 (Timepoints: pre-exposure, 30-min exposure, pre-fatigue, post-fatigue, and recovery) by 2 (Hand: left and right) repeated measure ANOVA indicated no significant three-way interaction for Condition x Timepoint x Hand (p = 0.16; η_p^2= 0.24). In addition, there was no significant two-way interaction for Timepoint x Hand (p = 0.63; η_p^2= 0.12), or Condition x Hand (p = 0.052; η_p^2= 0.45). There was, however, a significant two-way interaction for Condition x Timepoint (p < 0.001; η_p^2= 0.80). A follow up 3 (Conditions: Baseline, C-NORM, and C-HIGH) by 5 (Timepoints: pre-exposure, 30-min exposure, pre-fatigue, post-fatigue, and recovery) two-way repeated measure ANOVA collapsed across Hand indicated a significant interaction for Condition x Timepoint (p < 0.001; η_p^2= 0.78).

Three follow-up one-way repeated measure ANOVAs were performed to evaluate dorsal hand skin temperatures for timepoints across conditions. The results of the three one-way repeated measure ANOVAs indicated a significant difference in dorsal hand skin temperature at Baseline condition (p = 0.002; $\eta_p^2 = 0.49$), indicating pre-exposure < 30-min exposure and recovery (p < 0.001) and pre-fatigue < recovery (p = 0.003). In addition, there was a significant difference in dorsal hand skin temperature at C-NORM condition (p < 0.001; $\eta_p^2 = 0.91$), indicating pre-exposure > 30-min exposure, pre-fatigue, post-fatigue, and recovery (p < 0.001), and 30-min exposure > pre-fatigue, post-fatigue, and recovery (p < 0.001). Lastly, there was a significant difference in dorsal hand skin temperature at C-HIGH condition (p < 0.001; $\eta_p^2 = 0.67$), indicating pre-exposure > pre-fatigue, post-fatigue, and recovery (p = 0.002 – 0.01), 30-min exposure > pre-fatigue, post-fatigue, and recovery (p = 0.001 – 0.05), pre-fatigue > post-fatigue and recovery (p = 0.001 – 0.05), and post-fatigue > recovery (p = 0.036). Five follow-up one-way repeated measure ANOVAs were performed to evaluate differences in dorsal hand temperatures for each timepoint across condition. Results from the five one-way repeated measure ANOVA indicated no difference in dorsal hand temperatures for the pre-exposure timepoint across all three conditions (p = 0.17; $\eta_p^2 = 0.16$). There was, however, a significant difference in dorsal hand temperatures for the 30-min exposure, pre-fatigue, post-fatigue, and recovery timepoints (p < 0.001; $\eta_p^2 = 0.76 – 0.94$), indicating Baseline > C-NORM and C-HIGH conditions (p < 0.001). There was, however, no significant difference between C-NORM and C-HIGH for all environmental exposure timepoints (p = 0.21 – 1.00) (Figure 12).

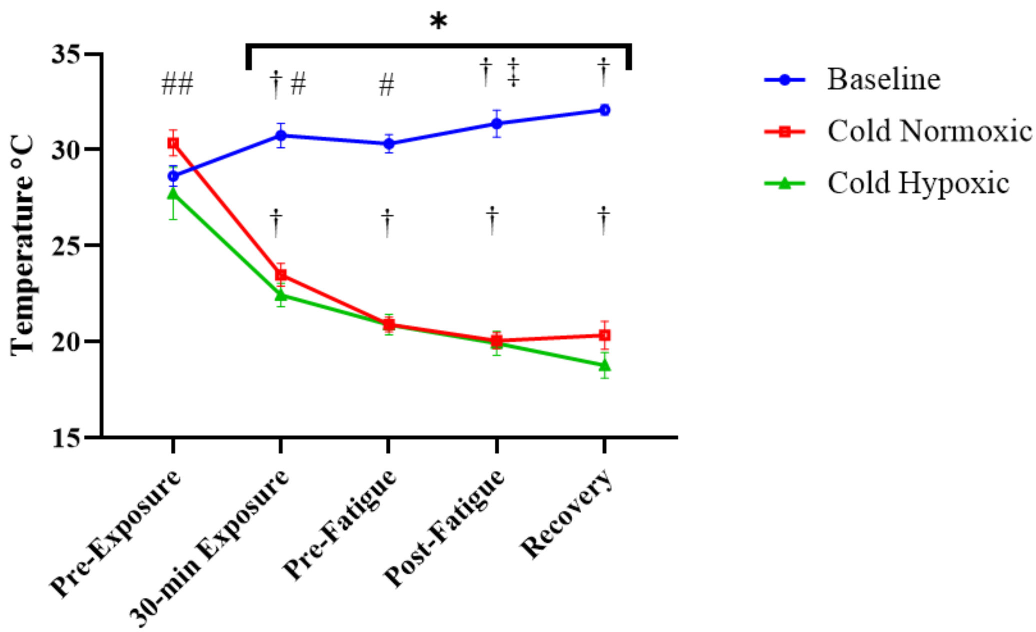

Figure 12. *Dorsal hand temperatures (°C) collapsed across hand (Mean ± SEM). * indicates Baseline > C-NORM and C-HIGH (p < 0.05). † indicates significant difference from pre-exposure timepoint (p < 0.05). ‡ indicates significant difference from pre-fatigue timepoint (p < 0.05). # indicates significant difference from recovery timepoint (p < 0.05). ## indicates C-NORM > Baseline (p < 0.05).*

For dorsal finger skin temperature, the 3 (Conditions: Baseline, C-NORM, and C-HIGH) by 5 (Timepoints: pre-exposure, 30-min exposure, pre-fatigue, post-fatigue, and recovery) by 2 (Hand: left and right) repeated measure ANOVA indicated no significant three-way interaction for Condition x Timepoint x Hand (p = 0.49; η_p^2= 0.14). In addition, there was no significant two-way interaction for Timepoint x Hand (p = 0.18; η_p^2= 0.30), or Condition x Hand (p = 0.30; η_p^2= 0.21). There was, however, a significant two-way interaction for Condition x Timepoint ($p < 0.001$; η_p^2= 0.83). A follow up 3 (Conditions: Baseline, C-NORM, and C-HIGH) by 5 (Timepoints: pre-exposure, 30-min exposure, pre-fatigue, post-fatigue, and recovery) two-way repeated measure ANOVA collapsed across Hand indicated a significant interaction for Condition x Timepoint ($p <$ 0.001; η_p^2= 0.82). Three follow-up one-way repeated measure ANOVAs were performed to evaluate dorsal finger skin temperatures for timepoints across conditions.

The results of the three one-way repeated measure ANOVA indicated a significant difference in dorsal finger temperatures at Baseline condition ($p < 0.001$; η_p^2= 0.54), indicating pre-exposure < 30-min exposure, post-fatigue, and recovery (p = 0.001 – 0.045), 30-min exposure < Recovery (p = 0.05), pre-fatigue < post-fatigue and recovery (p = 0.001 – 0.04). In addition, there was a significant difference in dorsal finger temperatures for the C-NORM condition (p < 0.001; $\eta_p^2 = 0.94$), indicating pre-exposure > 30-min exposure, pre-fatigue, post-fatigue, and recovery (p < 0.001), 30-min exposure > pre-fatigue, post-fatigue, and recovery (p < 0.001). Lastly, there was a significant difference in dorsal finger temperatures for the C-HIGH condition (p < 0.001; $\eta_p^2 = 0.74$), indicating pre-exposure > 30-min exposure, pre-fatigue, post-fatigue, and recovery (p = 0.001 – 0.005), 30-min exposure > pre-fatigue, post-fatigue and recovery (p = 0.001). Five follow-up one-way repeated measure ANOVAs were performed to evaluate differences in dorsal finger temperatures for each timepoint across conditions. Results from the five one-way repeated measure ANOVAs indicated a significant difference in dorsal finger temperature for the pre-exposure timepoint (p = 0.04; $\eta_p^2 = 0.33$), Baseline < C-NORM (p = 0.001). Additionally, there was a significant difference in dorsal finger temperatures for the 30-min exposure, pre-fatigue, post-fatigue, and recovery timepoints (p < 0.001; $\eta_p^2 = 0.85 – 0.96$), indicating Baseline > C-NORM and C-HIGH conditions (p < 0.001). There was, however, no significant difference between C-NORM and C-HIGH for all environmental exposure timepoints (p = 0.48 – 1.00) (Figure 13).

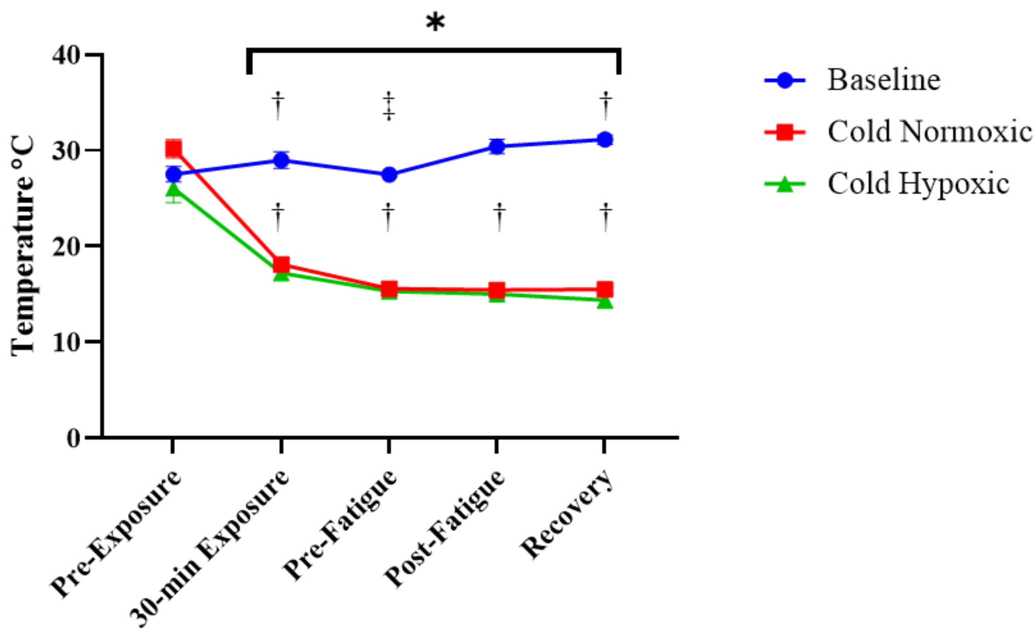

Figure 13. *Dorsal finger temperatures (°C) collapsed across hand (Mean ± SEM). * indicates Baseline > C-NORM and C-HIGH (p < 0.05). † indicates a significant difference from the pre-exposure timepoint (p < 0.05). ‡ indicates a significant difference from the recovery timepoint (p < 0.05).*

4.3 Near-Infrared Spectroscopy (%TSI)

For %TSI normalized to Baseline pre-exposure 10-s epoch, the 3 (Conditions: Baseline, C-NORM, and C-HIGH) by 5 (Timepoints: pre-exposure, 30-min exposure, pre-fatigue, and post-fatigue) repeated measure ANOVA indicated no significant two-way interaction for Condition x Timepoints (p = 0.19; η_p^2= 0.23). In addition, there was no main effect for Condition (p = 0.61; η_p^2= 0.10). There was, however, a main effect for Timepoints (p = 0.002; η_p^2= 0.560) indicating pre-fatigue < pre-exposure, 30-min exposure and recovery timepoints (p = 0.002 – 0.031), and post-fatigue < 30-min exposure and recovery timepoints (p = 0.006 – 0.042) (Figure 14).

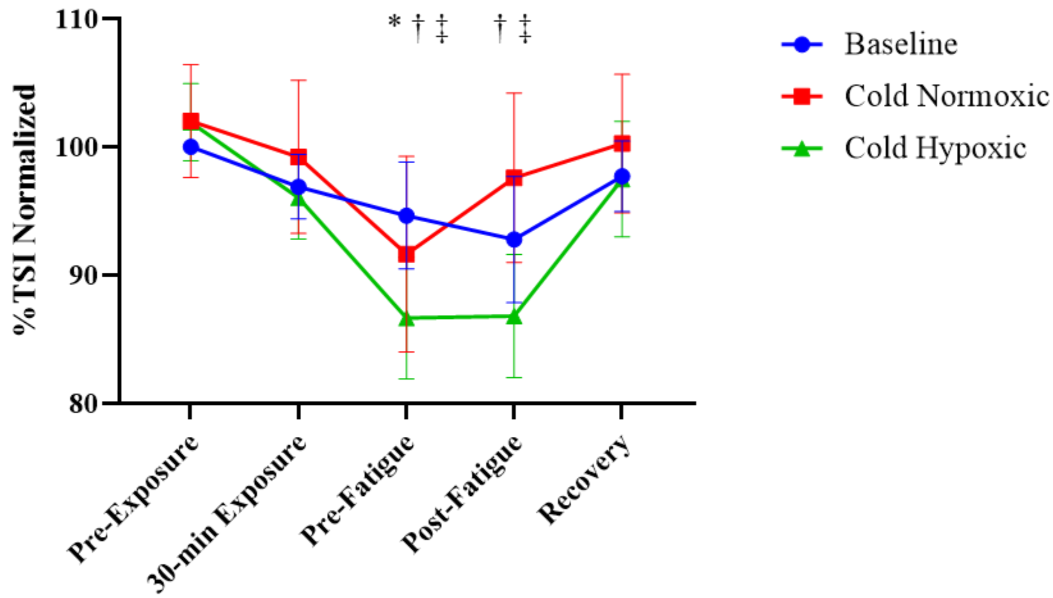

Figure 14. *Normalized %TSI (10-s epoch) across timepoints (Mean ± SEM). * indicates pre-fatigue < pre-exposure (p < 0.05). † indicates pre-fatigue < 30-min exposure and pre-exposure timepoints (p < 0.05). ‡ recovery > pre-fatigue and post-fatigue timepoints (p < 0.05).*

For %TSI during sandbag repetitions, the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 3 (Sets: set #1, set #2, and set #3) by 11 (Repetitions: 0, 10%, 20%, 30%, 40%, 50%, 60% 70%, 80%, 90%, 100%) repeated measure ANOVA indicated a significant three-way interaction for Conditions x Sets x Repetitions (p = < 0.001; η_p^2= 0.46). Three follow-up 3 (Sets: set #1, set #2, and set #3) by 11 (Repetitions: 0, 10%, 20%, 30%, 40%, 50%, 60% 70%, 80%, 90%, 100%) two-way repeated measure ANOVA were performed for each condition.

Results for the 3 (Sets: set #1, set #2, and set #3) by 11 (Repetitions: 0, 10%, 20%, 30%, 40%, 50%, 60% 70%, 80%, 90%, 100%) two-way repeated measure ANOVA for the Baseline condition indicated a significant two-way interaction for Sets x Repetitions (p = < 0.001; η_p^2= 0.86). Three follow-up one-way repeated measure ANOVAs were performed to evaluate the timecourse of change in %TSI for each set across repetitions. Results from the three one-way repeated measure ANOVAs for the Baseline condition indicated a significant difference for set #1 (p < 0.001; η_p^2= 0.65) indicating the initial repetition (0) > 30% - 100% repetitions (p = 0.02 –

0.04), 10% > 20% - 100% repetitions (p = 0.01 – 0.02), and 20% > 30% - 100% repetitions (p = 0.01 – 0.04) (Figure 6). Additionally, there was a significant difference in repetitions for set #2 (p < 0.001; η_p^2= 0.97) indicating initial repetition (0) > 10% - 100% repetitions (p < 0.001), 10% > 20% - 100% repetitions (p = 0.01 – 0.02), 20% > 30% - 100% repetitions (p = 0.01 – 0.02), and 30% > 40% (p = 0.04) (Figure 15). Lastly, there was a significant difference in repetitions for set #3 (p < 0.001; η_p^2= 0.97) indicating initial repetition (0) > 10% - 100% repetitions (p < 0.001), 10% > 20% - 100% repetitions (p = 0.01 – 0.02), 20% > 30% - 100% repetitions (p = 0.01 – 0.04), and 30% > 40% - 60% (p = 0.01 – 0.04) (Figure 6). In addition, eleven follow-up one-way repeated measure ANOVA were performed to evaluate %TSI for each repetition timepoint across each set. Results from the eleven one-way repeated measure ANOVA indicated no significant difference between the initial repetition across each set (p = 0.54; η_p^2= 0.12). There was however a significant difference for repetition timepoints 10% - 100% (p < 0.001; η_p^2= 0.95 – 0.99). indicating set #1 > set #2 and set #3 (p < 0.001) (Figure 15).

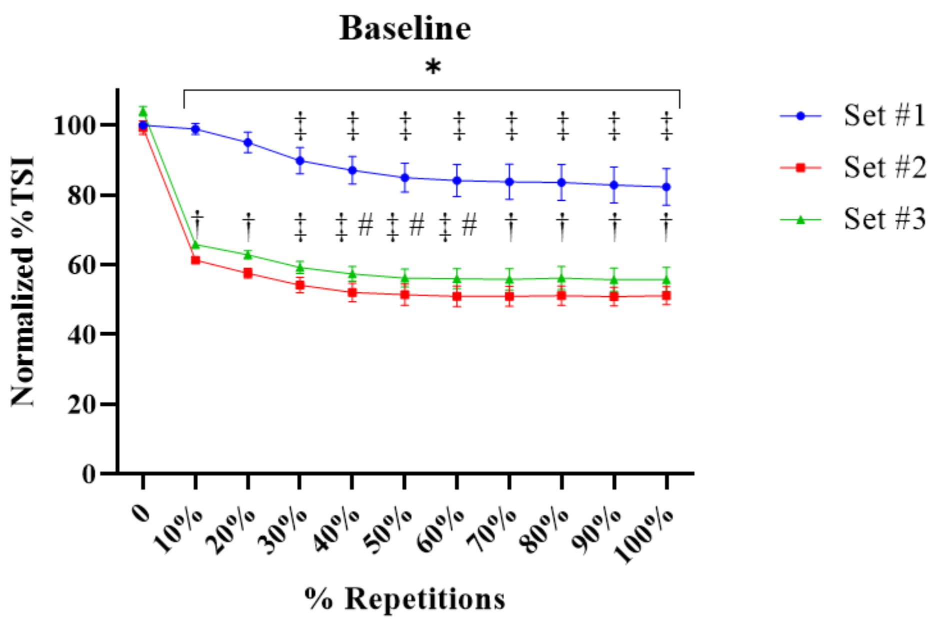

Figure 15. *Normalized %TSI for sandbag deadlift repetitions across sets (Mean ± SEM). * indicates set#1 > set#2 (p < 0.05). † indicates significant difference from initial repetition for Set #2 and Set #3 (p < 0.05). ‡ indicates significant difference from initial, 10% and 20% sandbag deadlift repetitions for all Sets (p < 0.05). # indicates significant difference from 30% sandbag deadlift repetitions for Set #2 and Set #3 (p < 0.05).*

Results for the 3 (Sets: set #1, set #2, and set #3) by 11 (Repetitions: 0, 10%, 20%, 30%, 40%, 50%, 60% 70%, 80%, 90%, 100%) two-way repeated measure ANOVA for the C-NORM condition indicated no significant two-way interaction for Sets x Repetitions (p = 0.15; η_p^2= 0.22) or main effect for Sets (p = 0.38; η_p^2= 0.91). There was, however, a significant main effect for repetitions (p < 0.001; η_p^2= 0.91). indicating initial repetition > 30% - 100% (p = 0.02 – 0.04) (Figure 16).

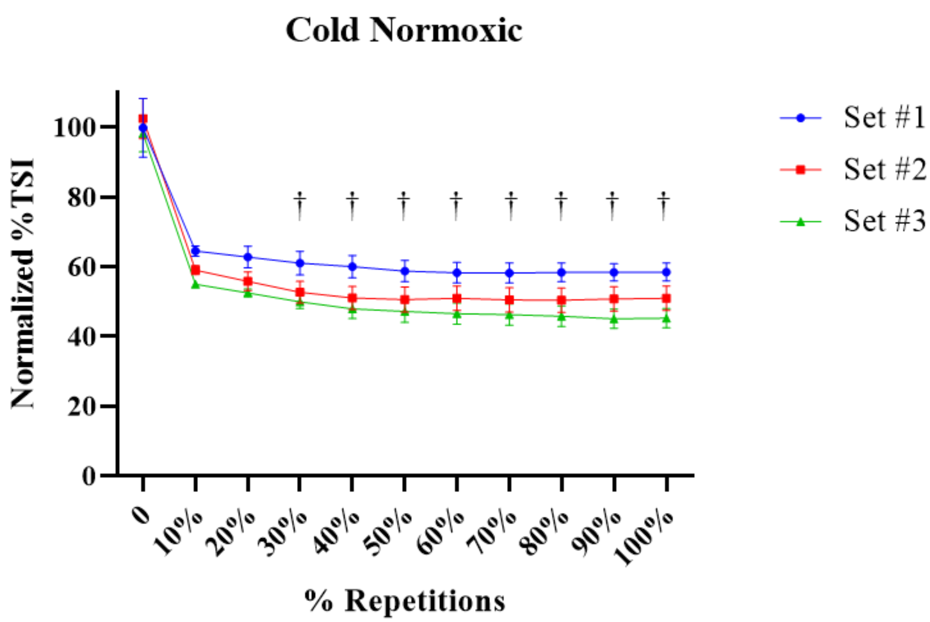

Figure 16. *Normalized %TSI for sandbag deadlift repetitions across sets (Mean ± SEM). † indicates a significant difference from initial repetition for all Sets. (p < 0.05).*

Results for the 3 (Sets: set #1, set #2, and set #3) by 11 (Repetitions: 0, 10%, 20%, 30%, 40%, 50%, 60% 70%, 80%, 90%, 100%) two-way repeated measure ANOVA for the C-HIGH condition indicated a significant two-way interaction for Sets x Repetitions (p = 0.01; η_p^2= 0.31). Three follow-up one-way repeated measure ANOVA was performed to evaluate the timecourse of change in %TSI for each set across repetitions. Results from the three one-way repeated measure ANOVA for the C-HIGH condition indicated a significant difference for set #1 ($p < 0.001$; $\eta_p^2 = 0.89$) indicating the initial repetition (0) > 40% - 100% repetitions ($p = 0.02 – 0.04$), (Figure 8). In addition, there was a significant difference in set #2 ($p < 0.001$; $\eta_p^2 = 0.81$), however, there were no significant pairwise comparisons. Lastly, there was a significant difference in set #3 1 ($p < 0.001$; $\eta_p^2 = 0.91$) indicating the initial repetition > 10% - 100% ($p = 0.02 – 0.04$) (Figure 8). In addition, eleven follow-up one-way repeated measure ANOVA were performed to evaluate %TSI for each repetition timepoint across each set. Results from the eleven one-way repeated measure ANOVA indicated no significant difference between all repetition timepoints (0 – 100%) across each set ($p = 0.2 – 0.9$; $\eta_p^2 = 0.01 – 0.35$). (Figure 17).

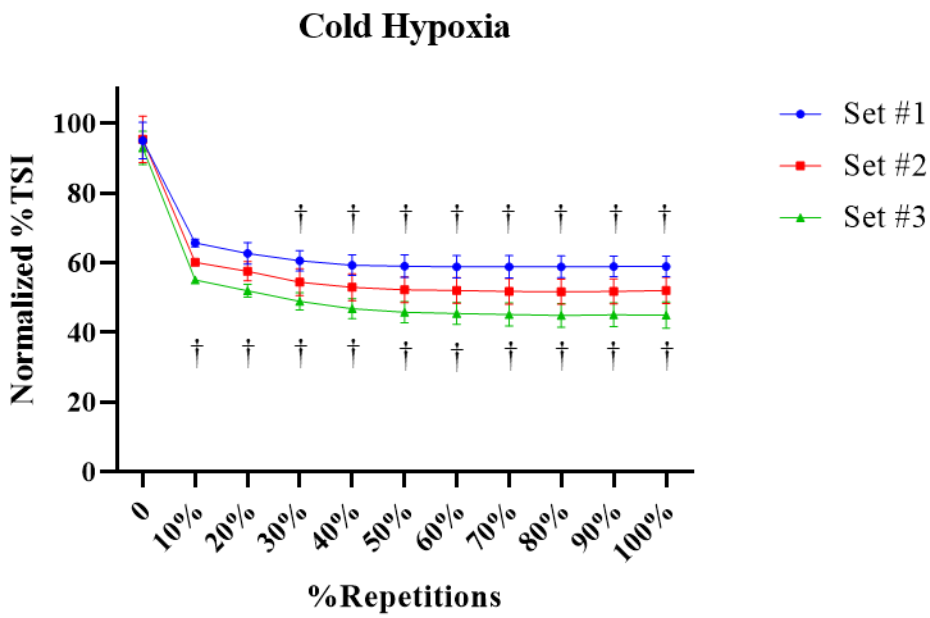

Figure 17. *Normalized %TSI for sandbag deadlift repetitions across sets (Mean ± SEM).). † indicates a significant difference from initial repetition for Set #1 and Set #3 (p < 0.05).*

4.4 Sandbag Deadlifts

For sandbag repetitions, the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 3 (Repetitions: set #1, set #2, and set #3) repeated measure ANOVA indicated no significant two-way interaction for Condition x Repetitions (p = 0.88; η_p^2= 0.01). In addition, there was no main effect for Repetitions (p = 0.10; η_p^2= 0.45) or Condition (p = 0.06; η_p^2= 0.45) (Table 1).

Table 1. Total number of repetitions performed during each set for the sandbag deadlift fatiguing protocol (50% of body weight)

	Condition		
Repetitions	Baseline *Mean ± SEM*	C-NORM *Mean ± SEM*	C-HIGH *Mean ± SEM*
Set #1	47.83 ± 12.25	51.00 ± 14.83	43.00 ± 12.64
Set #2	42.33 ± 10.48	44.17 ± 11.67	38.00 ± 24.64
Set #3	39.00 ± 9.17	42.50 ± 11.85	35.50 ± 9.14

4.5 Isometric Mid-Thigh Pull

For normalized isometric mid-thigh pull, the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 6 (Timepoints: Pre-exposure, 30-min exposure, Post set #1, Post set #2, Post set #3, Post-fatigue) repeated measure ANOVA indicated no significant two-way interaction for Condition x Timepoint (p = 0.50; η_p^2= 0.14). In addition, there was no main effect for Timepoint (p = 0.41; η_p^2= 0.15) or Condition (p = 0.45; η_p^2= 0.13) (Table 2).

Table 2. Normalized force production during Isometric Mid-Thigh Pull (N/kg)

	Condition		
Timepoint	Baseline *Mean ± SEM*	C-NORM *Mean ± SEM*	C-HIGH *Mean ± SEM*
Pre-exposure	15.95 ± 1.52	17.00 ± 1.90	17.13 ± 1.96
30-min exposure	15.01 ± 1.77	16.76 ± 1.73	15.63 ± 1.17
Post set #1	16.21 ± 1.43	16.97 ± 1.44	16.86 ± 1.78
Post set #2	15.25 ± 0.97	15.61 ± 1.15	16.49 ± 1.80
Post set #3	14.41 ± 1.32	15.58 ± 1.26	16.49 ± 1.45
Post-fatigue	15.04 ± 1.42	14.30 ± 1.58	15.58 ± 1.20

4.6 Pistol Shooting Performance

For marksmanship score, the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 2 (Marksmanship: pre-fatigued and post-fatigued) repeated measure ANOVA indicated no significant two-way interaction for Condition x Marksmanship (p = 0.09, η_p^2= 0.38) or main effect for Condition (p= 0.21, η_p^2= 0.27). There was, however, a significant main effect for Marksmanship (p= 0.02, η_p^2= 0.66) which indicated that Post-Fatigued > Pre-Fatigued (p = 0.02) (Figure 18).

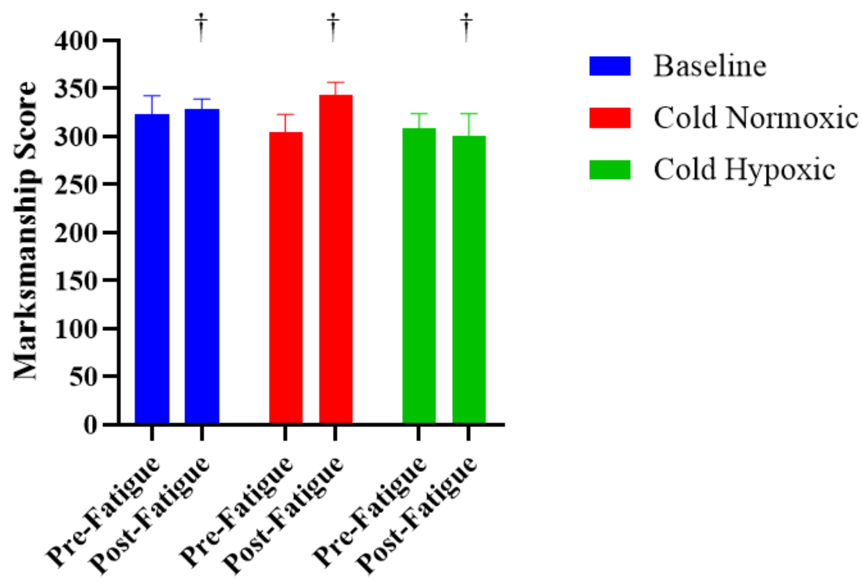

Figure 18. *Marksmanship scores during the pre-fatigue and post-fatigue timepoints (Mean ± SEM). † indicates post-fatigue marksmanship scores > pre-fatigue marksmanship scores (p < 0.05).*

For misses during the Match Target Drill, the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 2 (Misses: pre-fatigued and post-fatigued) repeated measure ANOVA indicated a significant two-way interaction for Condition x Misses (p = 0.02, η_p^2= 0.55). Two follow-up one-way repeated measure ANOVA was performed for conditions across the two shooting timepoints. Results from the one-way repeated measure ANOVA indicated no significant differences in the number of misses across the pre-fatigue timepoint (p = 0.30, η_p^2= 0.53) or post-fatigue timepoints (p = 0.16, η_p^2= 0.31). Three follow-up paired sample t-tests were performed to compare the number of misses during the Match Target Drill at the pre-fatigue timepoint to the post-fatigue timepoint across conditions. Results from the paired sample t-tests indicated that there were no significant differences in the number of misses between the pre-fatigue timepoint to post-fatigue timepoint during the Baseline and C-HIGH conditions (p = 0.31 – 0.42). There was, however, a significant difference between the number of misses between the pre-fatigue timepoint to post-fatigue timepoint for the C-NORM condition indicating that number of misses that occurred during the pre-fatigue timepoint > than the number of misses that occurred during the post-fatigue timepoint (p = 0.01) (Figure 19).

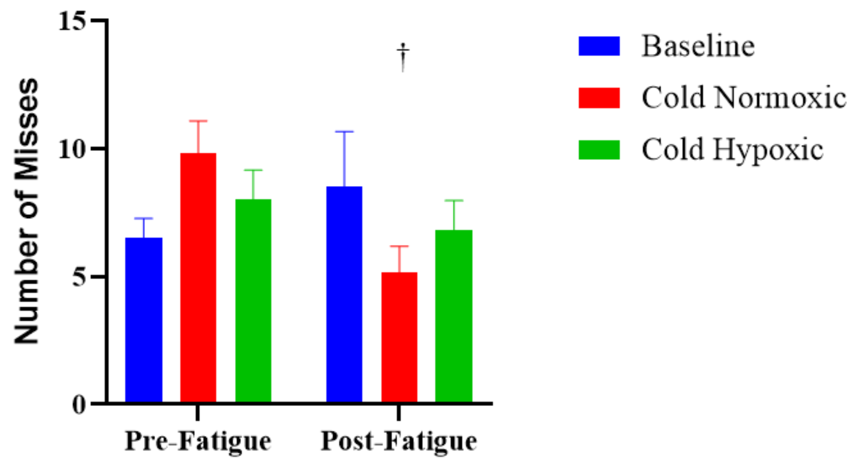

Figure 19. *The number of misses that occurred during the Match Target Drill during the pre-fatigue and post-fatigue timepoints (Mean ± SEM). † indicates the number of misses during the post-fatigue timepoint was significantly less than the pre-fatigue timepoint for the C-NORM condition (p < 0.05).*

For speed reaction drill, the 3 (Condition: Baseline, C-NORM, and C-HIGH) by 2 (Speed: pre-fatigued and post-fatigued) repeated measure ANOVA indicated no significant two-way interaction for Condition x Speed (p= 0.57, η_p^2= 0.11), main effect for Speed (p= 0.40, η_p^2= 0.14), or main effect for condition (p= 0.18, η_p^2= 0.29) (Table 3).

Table 3. Average reaction time to complete Speed Drill Scenario (sec).

	Condition		
Timepoint	Baseline *Mean ± SEM*	C-NORM *Mean ± SEM*	C-HIGH *Mean ± SEM*
Pre-fatigue	2.50 ± 0.24	2.48 ± 0.19	2.74 ± 0.24
Post-fatigue	2.23 ± 0.24	2.17 ± 0.15	2.72 ± 0.19

Chapter 5: Discussion

5.1 Marine Pistol Qualification Course

In the current study, pistol marksmanship scores during the Marine Pistol Qualification Course displayed an 8% increase from pre-fatigue to post-fatigue timepoints across all conditions (Figure 18). These results were similar to Tenan et al., 2017 who reported a 10-20% increase in marksmanship scores using an electronic-based M-4 rifle following a rucksack march consisting of 11.8 km carrying 48.5kg. Marksmanship performance is considered a complex motor skill that relies on a combination of psychological and physiological processes (Chung et al., 2009; Clements et al., 2018). Previous investigations have identified that an acute bout of exercise has the potential to improve motor skill development (Roig et al., 2013; Skriver et al., 2014) and cognitive performance immediately following exercise (Pontifex et al., 2009). These post-exercise improvements in motor skill and cognition may be related to an increased level of arousal improving performance during complex motor tasks (Statton et al., 2015). In addition, cold and hypoxic exposure did not independently alter marksmanship performance which suggested that the level of arousal was more influential to overall performance than independent and multi-stressor environments (Evans, 1966; Reading et al., 1994; Tikuisis & Keefe, 2007). Skriver et al., 2014 indicated that acute exercise can improve arousal levels via increased HR, and biomarkers such as norepinephrine and metabolic lactate accumulation following 20-min of intense cycling leading to 29% improvement during a visuomotor tracking task. Arousal has been associated with increases (Nibbeling et al., 2014; Tenan et al., 2017), decreases (Knapick, 1991) or the maintenance (Brown et al., 2013; Dadswell et al., 2015) of marksmanship performance following acute bouts of high-intensity sprints or long-duration ruck marches.

However, there are no known studies that have clearly measured the varying levels of arousals, biomarkers, or exercise-intensity differences in marksmanship performance.

The increased marksmanship scores in the current study and those of Tenan et al. 2017 were not in agreement with previous studies which reported no change or decreased marksmanship scores, shot accuracy, or shot grouping following an acute bout of exercise (Evans, 1966; Brown et al., 2013; Dadswell et al., 2015). Previous studies indicating a decrease in performance may be a result of greater physical demands of the fatiguing task, resulting in an over-arousal and metabolic requirement. For example, Knapick, 1991 indicated that 15% of soldiers sought medical attention following a 20 km march. According to the Yerkes-Dodson theory of arousal (Yerkes & Dodson 1908), performance increases with physiological or mental arousal until a finite point. When the level of stress or arousal becomes too high, performance decreases. This inverted “U” model can vary depending on the complexity and familiarity with the task (Yerkes & Dodson 1908; Lambourne & Tomporowski, 2010) and the level of stress (Yerkes & Dodson 1908; Lambourne & Tomporowski, 2010). Therefore, the findings of the current and previous studies suggested that exercise-related arousal levels may play an important role in marksmanship and military task performance (Tenan et al., 2017; Barnicle, 2019). Thus, post-exercise increases in marksmanship performance were likely a result of improved arousal through exercise, however, additional research is needed to determine optimal arousal levels in military and occupational marksmanship performance.

5.2 Match Target Drill

In the current study, the number of misses that occurred during the Match Target Drill was 47% less following an acute bout of exercise performed until volitional exhaustion indicating improvements in cognition and accuracy (Figure 19). The post-exercise improvement of cognition and accuracy may be explained by improved arousal similar to marksmanship as well as potential increases in blood flow (Brown et al., 2013; Nibbeling et al., 2014; Dadswell et al., 2015; Tenan et al., 2017). Additionally, repetitive sub-maximal exercise performed in cold may have attributed to an increase in metabolic heat production within the muscle through an increase in blood flow, and oxygen utilization within the muscle to improve ATP production during exercise (Saugen & Vollestad, 1996). When assessing the %TSI response within the VL during the C-NORM condition there was a 5% increase in %TSI from pre-fatigue to post-fatigue indicating an exercise-induced increase in sympathetic drive within the cardiovascular system ultimately increasing blood flow and oxygen utilization as reflected by %TSI (Taelman et al., 2011). Furthermore, the increase in metabolic heat produced through exercise may have shifted an individual's attentiveness from an internal focus to an external focus allowing their shooting performance to improve following exercise-induced fatigue (Tikuisis et al., 2002; Brown et al., 2013). Thus, the post-exercise improvement in the Match Target Drill reflected improved shot cognition and accuracy which may have been a result of increased arousal and blood flow.

5.3 Speed Drill

There was no difference in reaction time during the Speed Drill following an acute bout of exercise performed until volitional exhaustion during Baseline, C-NORM, or C-HIGH conditions. Although non-significant, a trend that displayed a decrease in reaction time following the sandbag deadlifts may have not been detectable due to the current study being underpowered (Table 3). For example, reaction time decreased by 11%, 13%, and < 1% for the Baseline, C-NORM, and C-HIGH conditions, respectively. These non-significant improvements may be attributed to arousal brought on by the stress of exercise alone (Brown et al., 2013), through the stress of exercise and cold (Enander, 1987), or reductions in arterial and cerebral oxygenation causing arousal to not alter reaction time speed (Ando et al., 2010). It is also plausible that the short duration (2.47 sec) of reaction time would need greater power to detect a difference, or that the duration of the task is too short that the influence of acute cold and hypoxia exposure was not sufficient to induce detectable changes. Lastly, it also possible that the severity of the acute cold and hypoxia exposure was not sufficient to elicit any detectable changes in shooting reaction time.

5.4 Pistol Environmental Conditions

All pistol shooting performance scenarios (Marine Pistol Qualification, Match Target, and Speed Drill) indicated that independent of exercise-induced fatigue, exposure to cold air (10°C) and a combined cold air (10°C) and hypoxia (simulated altitude of 3,800 m) environment for greater than 30-min did not affect marksmanship scores, the number of misses, and reaction time for the pistol (Figures 18 and 19, and Table 3). These results were similar to the findings of Tikuisis & Keefe, 2007 and Reading et al., 1994 which reported no changes in rifle marksmanship performance during cold exposures (0°C - 4.5°C) ranging in duration from 120-165-min while using an electronic-based C-7 or M-16 rifle. In addition, results from the current study are also in agreement with Moore et al., 2014 who reported exposure to simulated altitudes between 1,000m - 3,000 m produced no change in marksmanship scores assessed before exercise-induced fatigue. However, Moore et al., 2014 displayed a 17% decrease in marksmanship scores at a simulated altitude of 4,000 m (F_IO_2 = 12.7%) compared to sea-level, indicating a potential hypoxic threshold necessary for inducing hypoxic-related decreases in marksmanship performance (Moore et al., 2014). Despite the inability to directly postulate the independent effect of hypoxia on marksmanship performance within the current study, there was a non-significant 23% decrease in marksmanship following combined cold and hypoxia exposure. However, when accounting for the influence of cold exposure alone, which resulted in a non-significant 10% decrease in marksmanship performance. Although not significant, the 14% difference between C-NORM and C-HIGH may be a meaningful observation during the military missions and marksmanship task.

The number of misses observed during the Match Target Drill indicated no significant difference across environmental conditions for the pre-fatigue timepoint. However, based on the general trend for the number of misses that occurred across each condition may have indicated that the current study was underpowered for the identification of these differences. For example, compared to the Baseline condition, there was a 51%, and 23% increase in misses that occurred during the C-NORM and C-HIGH conditions, respectively. Which may have important implications in identifying performance during cold and combined cold and hypoxic conditions. Despite these non-significant differences between conditions, the general increase in the number of misses that occurred during C-NORM may be explained by subjective thermal discomfort and hand temperatures. For example, thermal discomfort caused by cold may have provided an alternative stimulus leading to a shift of attention from the marksmanship task resulting in a decrease in performance (Enander, 1987) Additionally, thermal hand temperatures may have influenced marksmanship performance. For example, previous studies have shown tissue temperatures below ≤ 20°C can influence nerve conduction velocity (Castellani & Tipton, 2016), and skin temperatures below ≤ 15°C may degrade manual dexterity performance (Hues, 1995; Giesbrecht et al., 1995; Daanen, 2009). Within the current study, the average skin temperature of the hands was approximately 20.9°C, whereas the average skin temperature of the fingers was 15.6°C throughout C-NORM and C-HIGH exposures indicating that these cold temperatures may have influenced the nerve conduction velocity with the hands and fingers and impaired motor coordination within the hands and fingers while performing the Match Target Drill. However, in previous investigations performed by Tikuisis et al., 2002 and Tikuisis & Keefe, 2007, the authors displayed finger temperatures between 10.8°C – 14.3°C and hand temperatures of 19.4°C had no effect on rifle marksmanship performance following prolonged cold exposure (0°C – 4.5°C). Thus, indicating that marksmanship is a multifaceted skill and identifying deviations in performance cannot always be described based on just physiological data or observations. Under the influence of environmental exposure alone, reaction time during the Speed Drill was unaffected by cold and combined cold and hypoxia exposure. Similar to the findings from the Match Target Drill, a lack of a difference in reaction time may be attributed to the study being underpowered for the identification of differences across conditions. For example, there was a non-significant < 1% decrease in reaction time for the C-NORM condition and a non-significant 10% increase in reaction time for the C-HIGH condition compared to Baseline. These findings may suggest that under the influence of environmental exposure alone, shooting accuracy may be more sensitive to degradations due to cold exposure compared to reaction time, whereas reaction time may be more sensitive to degradation due to hypoxia compared to accuracy. Indicating that acute exposure to individual and combined environmental stressors could alter different marksmanship performance metrics (i.e., speed and accuracy) to various degrees.

5.5 **Heart Rate Response**

The findings from the current study indicated that post-exercise HR during the recovery periods was similarly elevated throughout each environmental condition (Figure 10). It has been suggested that the increased metabolic demands associated with exercise led to increases in HR and stroke volume responses regardless of thermal exposure (Makinen et al., 2008; Sanchez-Gonzalez & Figueroa, 2013). These findings were in agreement with Makinen et al., 2008 and Gonzalez et al., 2018 which indicted that post-exercise HR responses were similar at 0-min Recovery (Baseline = 93.6; C-Norm = 85.3; C-High = 86.6 BPM) and at 10-min recovery (Baseline = 93.6; C-Norm = 85.3; C-High = 86.6 BPM) (Figure 10). Traditionally, cold exposure and hypoxia have both been reported to reduce post-exercise HR through an increase in metabolic heat production and regional blood distribution triggering a greater parasympathetic activation mediated by the baroreceptor reflex response (Haddad et al., 2012; Ikäheimo, 2018). The findings of the current study, however, indicated that the repeated sandbag deadlift exercise was a more potent regulator of HR than the influence of cold exposure or hypoxia. Thus, the findings of the current study indicated that acute cold and hypoxic exposure did not influence HR beyond the 11 to 14% elevation in HR associated with the repeated sandbag deadlift exercise.

5.6 SpO_2 Response

In the current study, there were no significant differences in SpO_2 values throughout the Baseline and C-NORM conditions (Figure 11). However, following exposure to a combined cold and hypoxic environment (C-HIGH) there was a decrease in SpO_2 following hypoxic exposure that remained lower throughout the duration of the visit (Figure 11). The 7 – 11% decrease in SpO_2 values following combined cold and hypoxic exposure was similar to the findings of Shin et al., 2020 who displayed a 12% decrease in SpO_2 during exposure to a simulated altitude of 3,500 m and cold temperatures between 28°C to 19°C. Thus, the findings of the current study indicated that the lower F_IO_2 during the C-HIGH condition resulted in systemic hypoxia reducing the overall availability of oxygenated hemoglobin. Furthermore, the combination of cold and hypoxia in the C-HIGH suggested the presence of cold-induced vasodilation (CIVD) within the fingertips that serves as a protection mechanism to reduce the risk of cold injuries. (Daanen, 2003).

5.7 Thermal Imagery

The general thermal patterns of the dorsal hand and the dorsal finger skin temperatures were similar throughout each condition (Figures 3 & 4). For both dorsal hand and dorsal finger skin temperatures, the Baseline condition produced a general increase in skin temperature from pre-exposure to the recovery timepoints whereas the C-NORM and C-HIGH conditions decreased at a similar rate from pre-exposure to the recovery timepoints (Figures 3 & 4). These findings were similar to Keramidas et al., 2014, O'Brien et a., 2015 and Keramidas et al., 2017 who reported no changes in dorsal hand or dorsal finger skin temperatures during localized cold-water immersion while breathing normoxic air (sea-level, [F_IO_2 = 21%]) and hypoxic air (3,000 m, [F_IO_2 = 14%] – 4,675 m, [F_IO_2 = 11%]). Taken together, these findings suggested that cold exposure is the primary factor associated with hand thermal temperatures and that acute hypoxic exposure (F_IO_2 = 14.3%) did not further influence thermal regulation (Simmons et al., 2007; Simmons et al., 2010). Thus, cold exposure likely resulted in the shunting of blood away from the extremities, towards the vital organs and working muscle throughout the exposure, fatiguing, and recovery timepoints to maintain optimal core body temperature during C-NORM and C-HIGH conditions. Therefore, these findings indicated that acute cold exposure at 10°C resulted in a decrease in hand temperature and that hypoxia had no added effects on the overall thermal regulation of the extremities.

For the Baseline condition, there was a general increase in hand and finger skin temperatures from pre-exposure to recovery timepoints (Figures 3 & 4). The approximate 4°C increases in hand and finger skin temperatures throughout Baseline exposure (24°C) were similar to those reported by Tikuisis & Keefe, 2007 which increased 3-4°C during 60-min of exposure at 22°C. The significant increases in hand temperatures observed within the current study may be attributed to normal fluctuation in sympathetic activity during the shooting and sandbag deadlift tasks altering skin temperature (Normell & Wallin, 1974). Specifically, the increased hand and finger temperature within the first 30-min of exposure could be by sympathetic compensatory mechanisms in preparation for the shooting and sandbag deadlift tasks (Wallin, 1990; Kistler et al., 1998). In addition, the 6% increase in skin temperature of the hand during the post-fatigue timepoint, and the 10% increase in skin temperature for both the hand and fingers following recovery may be due to the increase in exercise influencing systemic blood flow and oxygen to the peripheries (Tschakovsky et al., 1996; Crecelius et al., 2013) compared to pre-exposure.

5.8 Sandbag Deadlift Repetitions & Normalized MVIC (N/kg)

In the current study, there were no differences in the number of sandbag deadlift repetitions performed across each of the three conditions which indicated that exercise performed to volitional exhaustion in C-NORM and C-HIGH environments produced no change in exercise capacity compared to Baseline (Table 1). These findings were in contrast to Lloyd et al., 2016 who reported that 40-min of systemic exposure to cold (5°C, sea-level [F_IO_2 = 21%]) produced a 21% decline in time to exhaustion whereas combined cold and hypoxia (5°C, 4,100 m [F_IO_2 = 13%]) produced a 64% decline in time to exhaustion during repetitive leg extension movements compared to a normoxic, thermoneutral environment (23°C, sea-level [F_IO_2 = 21%]). Independent of hypoxia, cold exposure has been proposed to modulate exercise performance through behavioral mechanisms altering self-pacing strategies (Lloyd et al., 2016; Ferguson et al., 2018;), and through neuromuscular and mechanical factors limiting muscular contractility (Oksa et al., 2002; Castellani et al., 2010; Lloyd et al., 2011; Wakabayashi et al., 2015;). Independent of thermal exposure, hypoxia has been proposed to alter exercise performance primarily due to a reduction in arterial O_2 content limiting O_2 delivery to the working musculature (Fulco et al.,1995; Amann et al., 2006; Millet et al., 2019). Additionally, proposed mechanisms such as alterations in the hypoxia ventilatory drive and vasomotor activity within active musculature during exercise may also be a limiting factor in exercise capacity during acute hypoxia exposure (Kollai, 1983; Hoppeler & Vogt, 2001; Dinenno, 2015). Despite the independent effects of a single environmental stressor influencing dynamic exercise, Lloyd et al., 2016; Lloyd and Havenith 2016 proposed a novel trend in exercise performance that suggested combined cold and hypoxia exposure have an “additive” relationship indicating that the interaction of combined environmental stressors is influenced by the impact of each individual stressor together.

Similar to the sandbag deadlift, the MVIC during the mid-thigh pull exhibited a similar response across timepoints for the Baseline, C-NORM, and C-HIGH conditions (Table 2). These results are in contrast to Lloyd et al., 2015 who displayed a decrease in maximal isometric force during a brief isometric hand grip contraction. The pattern of response indicated that independent exposure to cold (5°C) and hypoxia (4,000 m [F_IO_2 = 13%]) led to a decrease in MVIC force by 14% in the cold and 8% in hypoxia compared to thermoneutral normoxia (22°C [F_IO_2 = 21%]). However, when cold and hypoxia were combined there was a 21% decrease in MVIC force compared to thermoneutral normoxia. The discrepancies between maximal isometric force production patterns between Lloyd et al., 2015 and the current study may be due to different movements and muscle activity. For example, Lloyd et al., 2015 performed maximal hand grip tasks that isolated forearm flexor muscles, whereas an isometric mid-thigh pull was used for the current study that utilizes multiple muscle groupings within the lower body and posterior chain. Potentially indicating that degradation in maximal isometric force production within a combined cold and hypoxia may be specific to isolated or smaller muscle groups. Alternatively, the differences in findings between the current study and Lloyd et al., 2015 and Lloyd et al., 2016 may be attributed to a dose-dependent response of cold and hypoxia as well as compensatory mechanisms and pacing associated with the shooting tasks. This hypothesis was supported by Oksa et al., 1997 who reported a dose-effect of cold exposure (10 to 20°C) to induce measurable decreases in maximal strength and power. In addition, previous studies (Tucker, 2009; Noakes, 2012; Jones et al., 2013) have indicated that pacing may occur subconsciously in an attempt to maintain or improve performance during the sandbag deadlifts and MVIC measurements.

The maintenance of sandbag deadlift repetitions across three sets to volitional exhaustion and no change in MVIC force across all timepoints suggested the presence of a subconscious pacing strategy aimed at optimizing the shooting performance scenarios. That is, subjects inherently paced themselves during the sandbag deadlift exercise and MVIC mid-thigh pull tasks resulting in a shift in exercise intensity leading to an increase in arousal that optimized shooting performance (Kamijo et al., 2004; Abbiss & Laursen, 2012). Collectively, the findings of the current study suggested an elevated state of arousal associated with compensatory mechanisms before the shooting scenarios and sandbag deadlift exercise that resulted in increased arousal that was similar across all conditions despite cold and hypoxic exposure. Future studies that aim to address the impact of a multi-stressor environment should monitor for potential pacing strategies during repetitive fatiguing exercise protocols. In addition, measuring sympathetic activity (i.e., heart rate, blood pressure, electrodermal activity, catecholamine release, etc.) throughout environmental exposure and after exercise can provide indications for increased arousal levels which may impact performance during cognitive and motor tasks such as pistol shooting and operation.

5.9 Near-Infrared Spectroscopy (%TSI)

In the current study, there was no detectable difference between the patterns of responses for %TSI from the vastus lateralis (VL) during Baseline, C-NORM, and C-HIGH while at rest (Figure 14). Following exercise, %TSI was reduced by 10% from pre-exposure to post-fatigue timepoint. These findings were similar to Davis et al., 2020 who reported a 68% and 69% decrease in absolute muscle oxygenation values following 3 sets of 15 repetitions during the back squat and the front squat, respectively. It has been suggested that a decrease in %TSI indicates an overall decrease in available oxygenation during exercise and can be attributed to a systemic reduction in oxygen availability (hypoxia), increased oxygen utilization, or a decrease in peripheral blood flow (cold) (Subdudhi et al., 2007; Scheeren et al., 2012; Barstow et al., 2019). It is important to note, however, that the literature on NIRS responses to single and multi-environmental stressors is lacking and additional research is needed to understand the unique physiological differences under environmental stressors and mechanisms behind these responses (Gagnon, 2014). In the current study, the decrease in %TSI (collapsed across conditions) at the pre-fatigue timepoint suggested an increase in oxygen utilization at the VL immediately prior to the sandbag deadlifts (Figure 14). This increased oxygen utilization prior to exercise supports the hypothesis of increased arousal and overarching compensatory mechanisms that aimed to increase the shooting performance (Secher & Volantis, 2006). That is, previous studies have indicated that an increase in arousal is accompanied by a concomitant increase in energy utilization coupled with increased activation of skeletal muscle (McIntyre et al., 2004). Thus, the decrease in %TSI prior to the sandbag deadlifts supported the hypothesis of increased arousal and compensatory mechanism aimed at optimizing shooting performance.

The decrease in %TSI at the post-fatigue timepoint, which remained similar to the pre-fatigue timepoint, indicated the maintenance of oxygenation to the active muscle immediately following the sandbag deadlifts and post-exercise shooting performance scenarios. During the repetitions to failure, there was a decrease in %TSI across all conditions and all sets (Figure 14) which indicated that the post-fatigue %TSI was maintained similar to pre-fatigue levels as a result of increased blood flow to the VL following the sandbag deadlift and shooting scenarios. Furthermore, the %TSI returned to pre-exposure levels following 10-min of recovery. The returning to pre-exposure levels following the completion of all shooting scenarios and sandbag deadlifts indicated a decrease in arousal and recovery following the completion of the study intervention. This increase in post-exercise parasympathetic activity may have improved systemic blood flow without any direct modulation of HR. The utilization of NIRS technology to measure muscle oxygenation (%TSI) and skeletal muscle metabolism may provide useful information for identifying systemic changes in blood flow and indications for autonomic nervous system activation during rest and following exercise.

5.10 Sandbag Deadlift Repetitions to Volitional Exhaustion (%TSI)

In the current study, the time course %TSI from the VL during the sandbag deadlift repetitions to volitional exhaustion indicated a general decrease in % TSI during each of the three sets (Figures 15, 16, and 17). During the Baseline condition, the %TSI throughout Set #1 was greater than Sets #2 and #3 at Baseline and all sets during C-NORM and C-HIGH. The greater %TSI during Set #1 at Baseline suggested sufficient blood flow, oxygenated hemoglobin, and myoglobin availability which was not maintained during Set #2 and Set#3. These findings were similar to Davis et al., 2020 who indicated a 15% and 12% increase in changes of muscle oxygenation values during Set #2 and Set #3 compared to Set #1 during 3 sets of 15 repetitions during the back squat exercise, respectfully. This may suggest that the 2-min rest between sets was not sufficient to fully recover the muscle resulting in a potential shift in the metabolic state within the VL mediated by an increase in HR, blood flow, and metabolites leading to a greater oxygen extraction.

For %TSI during C-NORM and C-HIGH, there were similar responses across all 3 sets of sandbag deadlifts which were also similar to those of Set #2 and #3 for Baseline (Figure 16 and 17). The decreases in %TSI throughout the sandbag deadlifts during C-NORM coupled with the maintenance of SpO_2 indicated that systemic oxygenation was sufficient for perfusion, but localized exchange at the activated muscles was the primary limiting factor (Subudhi et al., 2007). In addition, the similarities between the C-NORM and Baseline conditions Set #2 and #3 suggested the presence of a pacing strategy to limit the extent of the muscular fatigue likely to optimize post-exercise shooting performance. The primary difference between C-NORM and Baseline was the initial differences in Set #1 which suggested that the cold exposure experienced by C-NORM increased the metabolic demand during initial sandbag deadlift repetitions compared to Baseline, resulting in increased oxygen utilization. Therefore, these findings indicated that cold exposure alone may increase the demand for skeletal muscle oxygenation during the initial set of exercises requiring a greater flux of oxygenated hemoglobin available within the VL to contribute to exercise metabolism during subsequential sets.

The time course of responses during the sandbag deadlift for C-HIGH were similar to those of C-NORM and decreased during the repetitions to failure (Figure 16 and 17). The addition of hypoxia in C-HIGH exhibited general similarities to %TSI responses as C-NORM, however, the reduced SpO_2 coupled with lower %TSI suggested a systemic decrease in oxygenation. Specifically, during the C-HIGH conditions, there was a general decrease in SpO_2 and %TSI within the VL throughout exposure and during the sandbag deadlifts. (Figure 12 and 14). Taken together, these findings indicated a systemic reduction in oxygenated hemoglobin and myoglobin that was present throughout the duration of the C-HIGH condition mediated by the combined exposure of cold and hypoxia (Oguri et al., 2004; Yanagisawa et al., 2007). Despite the differences between the %TSI during Baseline, C-NORM, and C-HIGH, the repetitions performed remained unchanged, suggesting a similar pacing strategy employed in Baseline and C-NORM conditions to maintain autonomic system homeostasis through psychological exercise regulation, preserving physical exertion to improve shooting performance. This hypothesized psychological exercise regulation may be in part due to the memory and feedback from prior experience during the pre-fatigued shooting scenarios (Mauger et al., 2009) or due to knowledge of the task duration (Swart et al., 2009). Therefore, the alterations of skeletal muscle oxygenation within the VL due to combined cold and hypoxia exposure were improved to a sub-optimal point due to exercise improving skeletal muscle oxygenation and arousal that carried over into the pistol shooting scenarios.

5.11 Conclusion

Within the current study, the influence of cold exposure (C-NORM) and combined exposure to cold and hypoxia (C-HIGH) was investigated to identify changes in performance during pistol shooting performance due to environmental exposures independently and following a fatiguing sandbag deadlift task performed during C-NORM and C-HIGH conditions. The results from the current study indicated that C-NORM and C-HIGH conditions did not influence pistol shooting performance metrics during the Marine Pistol Qualification Course, Match Target Drill, and Speed Drill. However, marksmanship performance (score) improved following the fatiguing sandbag deadlift protocol despite environmental exposures to C-NORM and C-HIGH conditions. In addition, pistol shooting accuracy increased following the fatiguing sandbag deadlift protocol during the C-NORM condition, but reaction time did not change following the sandbag deadlifts performed during the Baseline, C-NORM, and C-HIGH conditions. In context to the findings of dynamic and isometric muscular performance, there was no change in repetitions to fatigue during the sandbag deadlifts and no change in maximal isometric strength during the mid-thigh pull throughout all exposure conditions (Baseline, C-NORM, and C-HIGH). These findings suggested that individuals employed a self-pacing strategy during the sandbag deadlift movements to preserve performance for the pistol shooting scenarios and regulate their systemic thermal and hemodynamic homeostasis. This hypothesized, self-pacing, psychological regulatory mechanism was supported by the measured systemic oxygenation

(SpO_2), local skeletal muscle oxygenation (%TSI), and thermal temperatures within the hands and fingers. In addition, this self-pacing strategy likely modulated physical exertion during the sandbag deadlifts causing an increase in arousal which was indicated through an increase in sympathetic activity (increased HR, and a maintained systemic and localized oxygenation [SpO_2 and %TSI]) observed throughout and immediately following the fatiguing sandbag deadlift movements. This heightened level of arousal due to greater sympathetic activation was likely the major contributor to the improvements in pistol marksmanship and accuracy despite the influence of environmental exposure. Therefore, findings from the current study suggested that acute exposure to cold (10°C) and combined cold and hypoxia (10°C; F_IO_2 = 14.3% [3,080 m]) did not have an influence on pistol shooting performance (marksmanship, accuracy, or reaction time). However, when pistol shooting performance was re-evaluated following the repetitive sandbag deadlifts performed until volitional exhaustion, there was an improvement in marksmanship scores across all environmental conditions, and improvements in pistol shooting accuracy during the C-NORM condition, despite no detectable changes in sandbag deadlift repetitions observed throughout each condition. These findings suggest that self-pacing strategies and increased levels of arousal are important contributors to pistol shooting performance during cold and combined cold and hypoxia environmental stress. Future studies examining the effects of marksmanship performance and fatigue within multi-stressor environments should consider including arousal and pacing strategy assessments.

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Appendix A

U.S. Marines Combat Pistol Program Scorecard:

COMBAT PISTOL PROGRAM SCORE CARD

INSTRUCTIONS:

ENTRIES ON ALL SCORE CARDS WILL BE MADE IN INK OR INDELIBLE PENCIL. WHEN CORRECTIONS ARE NECESSARY, EACH CORRECTION WILL BE INITIALED BY RANGE PERSONNEL.

LNAME:	INT:	GRADE:
ORGANIZATION:		
EDIPI:	DATE:	
IN ENTERING PISTOL HITS, THE VALUE OF SHOTS WILL BE MARKED HIGHEST TO LOWEST WITH A "VM" REPRESENTING A MISS OR "0" FOR A ZERO VALUE SHOT. MISSES MUST BE VERIFIED, ZERO VALUE SHOTS MAY BE ENTERED BY THE COACH.	TGT:	RELAY:
	COURSE ☐ PRE-QUALIFICATION	
	CALIBER ☐ M9 ☐ OTHER ___	

YARD	TYPE	VALUE OF HITS								TOTAL
7	CP								MAX 60	
7	FAILURE CHEST								MAX 40	
7	FAILURE HEAD								MAX 20	
7	CP/SR								MAX 40	
15	CP								MAX 60	
									MAX 60	
15	CP/SR								MAX 40	
25	THREAT ASSESS								MAX 40	
25									MAX 40	

TOTAL MAX SCORE 400	Score:
SCORE CORRECTIONS/NOTES:	
SCORER SIGNATURE:	VERIFIER SIGNATURE:
SHOOTER SIGNATURE:	

Score: 0-263=UNQ 264-323=MM 324-363=SS 364-400=EX

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Appendix B

General Rules for a Fast Draw Competition Adapted from the World Fast Draw Association (WFDA):

1. Prior to receiving the signal to draw, the contestant's hands shall be placed in the following manner.

a. The gun hand may be on or touching the gun. The trigger finger shall not enter the trigger guard.

b. The fanning hand shall not purposely come into contact with the gun, holster, belt, or any part of the rig prior to the start signal. Nor shall the fanning hand come into contact with the body, the other hand, or used as a pivot point about which to make the draw.

c. It must be reasonably evident to the Line Judge that the shooter is not touching the gun with the fanning hand. Penalty: First violation, warning. Second violation will result in the loss of that shot. Only one warning will be given for each event.

d. After the shooter commands have been given, the contestant shall not be falling back and become off-balance, if it is obvious to the officials that he/she is using this method consistently to anticipate the light he/she will be first warned and then the second time will be a loss of shot.

e. Prior to shooting and setting gun in holster and the signal

2. Contact with the gun caused by a flinch due to a sudden, loud noise or other disturbance, the contestant will receive a re-shoot. The contest officials in the immediate area shall have sole authority, by a majority vote, to grant a re-shoot.

3. Any attempt to draw and fire on a light, whether it is a quick or slow light, will be considered a legal draw. Only the Line Official may determine if a disturbing flash of light occurred, in which case, the contestant would receive a re-shoot. The Line Official's decision is final.

4. Once the "shooter set" command has been given there will be no call off allowed by any competitor

5. The ready command may be given by either the contestant or clock operator. If the clock operator gives the signal, it shall be stated as" Shooter on the line, shooter set". In walking events, the shooter may walk when ready or take a command from the clock operator in which case it shall be stated as "Shooter on the line, shooter walk".

6. After the command is given, the random signal to draw shall not come on before two (2), nor later than five (5) seconds.

7. In all standing events, the competitor's gun, holster and feet must be behind the shooting line. Note: If a piece of tape is used as a line, both feet must be behind the edge closest to the shooter.

Vita

Owen F. Salmon was born in Wakefield, Nebraska. Before attending the University of Texas at El Paso (UTEP), he attended the University of Nebraska-Lincoln (UNL) where he earned a Bachelor of Science in Exercise Science and gained research experience within the Human Performance Laboratory at UNL. In addition, Owen has previous job experience in early-phase pharmaceutical research, clinical exercise testing, personal training, and coaching.

While completing his Master's degree at UTEP, Owen held a position as a Graduate Research Assistant where he assisted in the development of the Human and Environmental Physiology Laboratory (HEPL). Owen's current research focus is applied to understanding changes in human performance during acute exposures to thermal stressors and hypoxia. Specifically, Owen is focused on applying his research to military and blue-collar occupations to improve safety and track performance during various environmental exposures.

Upon completion of Owen's Master's degree in May 2021, he will then be enrolling into the College of Health Sciences, Interdisciplinary Health Sciences Ph.D. program at UTEP to continue with his research initiative (Fall, 2021).