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EFFECTS OF HEAT STRESS AND EXERCISE ON SHOOTING PERFORMANCE

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By

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HEAT STRESSES EFFECTS ON SHOOTING PERFORMANCE AFTER EXERCISE

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Abstract

Purpose: The purpose of this study was to evaluate the effects of exercise and acute heat stress on marksmanship performance measures of accuracy, precision, aim time, and distance travelled by the point of aim in trained US military veterans. **Methods:** Subjects (*N*=8) (height 184.1 ± 10.9 cm (*SD*), weight 92.1 ± 10.6 kg, 21.1 ± 8.9% body fat, VO_{2max} 47.25 ± 7.36 mL/kg/min, age 26.8 ± 4.3 yrs.) completed one-hour of walking at 50% VO_{2max} in a hot (35˚C, 30% maximal relative humidity) or cool (22˚C, 30% maximal relative humidity) environment. Core temperature, heart rate (HR), and physiological strain index (PSI) were recorded throughout the exercise period. Shooting assessments and nude body weights were completed before and after exercise to determine % body weight loss, accuracy, horizontal and vertical deviation, precision, aim time, and distance travelled by the point of aim. **Results:** Core temperature, HR, and PSI increased from rest (35.7 ± 4˚C; 88 ± 4bpm) in both cool (37.8 ± .5˚C; 143 ± 20bpm, 5.5 ±1.6) and hot (38.5 ± .4˚C; 167 ± 13 bpm, 7.8 ±1.11) conditions at 60 minutes but were significantly greater in hot compared to cool in the latter half of the trial. Percent body weight loss was greater in the hot (1.5 ± 0.5 %) compared to cool (0.9 ± 0.5 %) trials. Aim time decreased for cool (3.2 ± 0.4 sec) and hot (2.9 ±0.3 sec) trials compared to rest (4.1 ± 0.4 sec). Vertical-deviation increased in the kneeling position (15.2 ± 1.3 mm *SE*) compared to prone (10.7 ± 1.38 mm *SE*) but standing (14.1 ± 1.2 mm *SE*) was not significantly different from either. There were no changes from rest for accuracy, distance travelled, or precision in either hot or cool trials. **Conclusion:** Despite elevated levels of physiological strain there were no decrements in marksmanship performance due to exercise or heat stress. Kneeling may alter vertical deviation more than prone or standing shooting positions during marksmanship tasks. These data also indicate a need for more work related to prolonged, elevated PSI and/or % body weight losses commensurate with or exceeding the suggested 2% criteria.

Keywords: Marksmanship, Heat, Military, Exercise

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Chapter One: Introduction

Introduction

Marksmanship is a highly skilled task that requires cognitive, visual, and neuromuscular function to be successful (Headquarters, 2008; Hatch, *et al.* 2009). The US Army identifies steady position, aiming, breathing, and trigger control as critical skills for accurate and precise shot placement (Headquarters, 2008). Marksmanship is often accessed based on three parameters; accuracy, precision, and time between shots, this is because they are easy to measure and are the goal of the sport or job (Johnson & Kobrick 1997, Headquarters 2008). Accuracy is the distance from the desired point of impact of the projectile and the actual point of impact on the target. Precision is the smallest diameter circle that can be used to enclose all shots placed within a group. Time between shots is the time between two consecutive shots, which is a crucial skill that often determines a winner in recreational shooting or survival in occupational settings. The training of a good marksman takes many hours and is extremely cost intensive (Headquarters, 2008) the US Army marksman training includes 103 hours of marksmanship training before a soldier is allowed to qualify. An optical targeting system can be employed for new and experienced marksmen during training to try and offset these costs (Headquarters, 2008). These often are a three-part system that can be used with any firearm in any setting from the shooting range to within a house. They consist of a laser emitting unit that can easily attach to the barrel of most guns, a system specific reflective target, and a computer which is used to collect and display the data (Noptel Expert Range Optical Targeting System, Oulu, Finland). These systems have been validated to improve shooting technique and be accurate for research purposes (Tikuisis 2002, Tikuisis & Keefe 2005, Johnson & Kobrick 1997).

Recreational and occupational athletes are often exposed to environmental conditions such as altitude, cold, and heat and are still required perform maximally. Heat stress has been well known to effect human performance including cognitive function, vision, and neuromuscular control in both recreational and occupational athletes (Walter, E and Carraretto, M 2016, Distefano *et al.* 2012, Morley *et al.* 2011). Heat stress is often defined by a rise in core temperature more than 1º C with maximally fatiguing heat stresses in laboratory settings being recorded at 40.1º C when doing strenuous tasks in the heat (Walter & Carraretto 2016, Gonzalez-Alanso *et al.*1999). A study examining jump landing and postural control before and after heat exposure found a significant decrease in scores on both tests indicating that heat decreased neuromuscular control (Distefano *et al.* 2012). Maximal Voluntary Contraction (MVC) and Motor Evoked Potentials (MEP's), indicators of muscle function and neural input to muscle, have been found to decrease. This implies both peripheral and central muscular control mechanisms were fatigued when core temperature was raised due to passive heating (Gaoua *et al.* 2011a, Gaoua *et al.* 2011b). Central fatigue indicates cognitive function is impaired which has been found in other studies that examined both memory and attention after heat exposure (Gaoua *et al.* 2011b, Sun *et al.* 2011). In Gaoua *et al.* (2011b) participants had a decrease in short-term memory and pattern recognition which is critical for determining friendly and hostile targets' location and movements during tactical engagements for occupational marksmen. Pre-attentive responses to audio signals were found to slow when exposed to heat. This is also critical to occupational marksmanship to be able to quickly and effectively observe, prioritize, and engage incoming hostile threats at all times (Sun *et al.* 2011).

Previous research has shown mixed effects on performance in occupational marksmen when exposed to either heat stress and strain at low to high levels (Johnson and Kobrick, 1997, Tikuisis 2002, Tikuisis and Keefe 2005). When investigating heat strain Tikuisis P. and Keefe A. (2002, 2005) found that there was no change in marksmanship accuracy or time to detect targets independent of core temperature reaching 39º C and up to 3.2 % body weight loss. While a study done looking at high heat stress by Johnson R. and Kobrick J. (1997) found that subjects had a 20-56% decrease in shooting accuracy when exposed to heat in chemical protective clothing. They also found that precision was not affected when subjects were allowed to select their own shooting speed but when they had to shoot within a time frame they found a decrease in precision of 20%. While no other research has been done examining the relationship between heat and shooting performance anecdotal evidence suggests a negative relationship between the two.

Problem

The purpose of this study was to examine the effects of heat stress, dehydration, and exercise on shooting parameters such as accuracy, precision, time between shots, and distance travelled by point of aim. It will also look at the effect of shooting position on shooting parameters.

Null Hypotheses

There will be no difference in shooting accuracy between exercise condition and shooting position

There will be no difference in precision between exercise condition and shooting position

There will be no difference in time between shots between exercise conditions or shooting positions.

There will be no difference in point of aim displacement between exercise condition and shooting positions.

There will be no difference in core temperature between each exercise condition.

There will be no difference in heart rate between exercise conditions.

There will be no difference in percent body weight loss between exercise conditions.

Significance of Study

This study will provide greater insight to the effect of heat stress effects on accuracy, precision, time between shots, and distance traveled by point of aim. Recreational and occupational athletes will benefit by using this information for the training or production of interventions to attenuate heat stress in while shooting.

Rationale of Study

This study will allow for greater comparison among the current pool of research by showing the effects that different shooting positions have on shooting performance. This is because many of the current marksmanship research uses different shooting positions making direct comparison difficult. It will also provide another look at heat stress and marksmanship performance. This study will provide a baseline shooting metric that other studies can compare too.

Limitations

1. Subjects will provide their own food and log their own activity for the 24 hours before arriving at the lab. They will also be expected to replicate their food and activity when returning for their second experimental visit.
2. Subjects must arrive at the lab at similar times of the day for both intervention trials to prevent influence on performance.
3. This study is looking at the combined effects of heat stress, dehydration, and exercise effects on shooting.
4. Only military marksmen who have obtained the marksmanship ribbon will be included in the study.
5. Only treadmill exercise will be examined as the source of exercise.

Delimitations

1. Due the need for skilled shooters only current or recent veterans will be recruited for this study.
2. Only recreational athletes will be included in this study.
3. Shooting distances will be held constant at 100 m.
4. Only a M-4 replica rifle will be used as the shooting platform during this study.
5. Subjects will be limited to shooting from a prone, kneeling, and standing position.
6. No personal protective equipment will be used during shooting.

Definition of Terms

1. Accuracy- is the straight-line distance (mm) from the center of the target. All shots were averaged into a single positional score
2. Horizontal deviation- Absolute value of the distance to the right or left of the center of the target.

3. Vertical deviation- Absolute value of the distance above or below the center of the target.
4. Precision- This will be the diameter (mm) of circle that must be used to enclose all shots in a group.
5. Time between shots- The time after the first shot is taken till the next sequential shot.
6. Total distance travelled by the point of aim - is the total distance traveled by the point of aim between each shot.
7. Optical targeting system- A laser emitting shot tracking system that is used to mimic shooting with a real gun. It consists of a laser emitting unit attached to the barrel of the rifle, a scaled reflective target, and a computer system to collect and display shooting data.
8. Core temperature- The rectal temperature in degrees Celsius that subjects obtain throughout heat and exercise protocol.
9. Heat Stress- The core temperature that is reached by subject throughout heat and exercise protocol.
10. Physiological Strain Index (PSI)- An index that uses core temperatures and heart rate to assess the heat strain, on a 0-10 scale, experienced by an individual.

Chapter Two: Review of Literature

Hyperthermia

Thermoregulation

The body exists within a narrow range of body temperatures and if it fluctuates more than a few degrees performance may be hindered, and death can possibly occur at the highest levels (Periard *et al.* 2010). Light heat stress has been defined as a rise in core temperature more than 1ºC, with maximally fatiguing heat stresses in the laboratory at 40.1 º C when performing strenuous tasks (Walter & Carraretto 2016, Gonzalez-Alanso *et al.*1999). Hyperthermia can be induced by passive or active heating mechanisms. Passive heating requires the individual to be in an environment that is warmer than their body and for their body to be unable to compensate for the rise in core temperature (Periard *et al.* 2011). Exercise induced hyperthermia, which is much more common in lab and recreational settings, is due to metabolic heat production. In humans about 70% of energy that comes from ingested food is released as heat, that the body must dissipate otherwise it will raise core temperature (Gonzalez-Alonso J *et al.* 2000). At rest this heat load is low do to the low energy demand but as energy demand increases with exercise the amount to heat that is produced increases dramatically (Gonzalez-Alonso J *et al.* 2000). The greatest hyperthermia effects are seen when both active and passive heating mechanisms combine.

As hyperthermia develops the body tries to off load this heat in two major ways, convection-conduction (skin blood flow), and evaporation (sweating) (Gonzalez-Alonso, J 2012, Maughan, R Shirreffs 2004). The convection-conduction model starts with the convective heating of the blood as it passes through the active muscles, removing some of the heat load from that region of the body (Gonzalez-Alonso, J 2012). This heated blood is then sent to cutaneous capillary beds around the body to be cooled. As the heated blood passes through the cutaneous capillary bed the surrounding cooler skin is convectively heated leading to the recycling the heat load capacity of the blood. The heated skin then conductively and convectively off loads the heat to the surrounding environment effectively removing the heat stress from the body. This process is extremely powerful and has limited effect on performance until maximal heat stresses, due to the redistribution of blood flow to the periphery away from active muscle (Gonzalez-Alonso, J 2012). This method works well for environmental conditions in which the environmental temperature outside the body is less than that of the skin temperature (~32 º C). It has been found that the gradient of core temperature to outside environment is a crucial determinate of human performance in hot environments (Cuddy, Hailes, Ruby 2014). This gradient can be negatively affected by increased humidity, increased air temperature, and protective clothing limiting heat exchange with the surrounding. This can be hazard for occupational athletes who are required to be active in hot environment and to wear protective clothing, such as wildland firefighters or military personnel (Cuddy, Ruby 2011).

The second main method of cooling the body from a heat stress is the evaporation of sweat from the skin and respiratory systems. This method is useful for assisting the convection- conduction method by restoring or intensifying the skin to core temperature gradient

(Maughan R, Shirreffs S, 2004). The downside to this method is that while it does assist with the cooling of the body it does so at the expense of its our own hydration levels. If heat stress continues for prolonged periods of time the dehydration levels can begin to effect human performance in addition to the decreases due to the heat stress. Dehydration levels are often measured in percent body weight loss and it has been seen that a percent body weight loss of 1.1 – 2% can decrease human performance (Distefano *et al.* 2012, Maughan R, Shirreffs S, 2004,). Dehydration causes a drop-in blood plasma volume which drives an increase in heart rate to maintain the cardiac output needed for exercise. This shift in heart rate to maintain cardiac output decreases the potential cardiac supply to muscles for performance needs (Gonzalez-Alonzo, J *et al.* 1999, Periard *et al.* 2010).

Human Performance and Heat

If these two methods of heat mitigation are unable to decrease the heat stress then human aerobic performance, cognitive function, and neuromuscular control have been seen to decrease. Previous research has indicated that core temperatures >38.5º C are a high heat stress and can lead to these decrements (Periard *et al.* 2010). In a study that was examining well trained cyclist it was seen that regardless of starting core temperatures subject terminated exercise at core temperatures of 40.1º C (Gonzalez-Alonzo, J *et al.* 1999). It was also seen that subjects who started with an esophageal temperature of 38º C had 44% shorter exercise duration compared to those who started with an esophageal temperature of 36º C. It has been seen in a wildland firefighter, that despite preventing dehydration by taking in large amounts of water, that at a core temperature of 40.1ºC work had to be terminated due to heat exhaustion (Cuddy & Ruby 2011)

Cognitive function is also affected by moderate to high heat stress much like aerobic performance (Walter and Carraretto 2016). Attention and memory are often affected by moderate to high heat stress level, with coma and death happening at critically high temperatures in extreme circumstances (Periard *et al.* 2010). Prolonged high heat stress has been shown to effect these functions the most but acute exposures can lead to dysfunction as well and have lasting effects for 60-120 minutes after exposure (Gaoua *et al.* 2011b, Morely *et al.* 2013). It has been found that only prolonged heat exposures or core temperature approaching 40º C effect subject's performance on attention tests (Gaoua *et al.* 2011b, Morely *et al.* 2013). In a study by Morely *et al.* who administered the CANTAB battery to firefighter found that reaction time, rapid visual identification, short term memory, and pattern identification can be negatively affect for up to 120-minutes post heat exposure (2012). All of which are critical skill for marksmen.

Neuromuscular control has been found to decrease with exposure to moderate and high heat stress (Periard *et al.* 2011). It was found that both central and peripheral elements of decrease when exposed to both active heat stress and passive heating (Periard *et al.* 2011). In this study they found that 42% of the decrease in muscle force production was due to central fatigue versus peripheral fatigue (Periard *et al.* 2011). In another study that looked at jump landing and postural control it was found that both dehydration and hyperthermia can decrease these performances leading to a higher risk of injury (Distefano *et al.*2013). In the jump landing scores subjects performed 25% worse than when hydrated and in temperate temperatures. Postural control was found to decrease about 8-fold when dehydrated and under heat stress than scores collected when subjects were hydrated and cool (Distefano *et al.*2013). These studies how that there is a decrease in neuromata control after exercising in the heat.

Physiological Strain Index (PSI)

Another method of monitoring hyperthermia other than core temperature and dehydration levels is to use the Physiological Strain Index (PSI) (Moran D, Shitzer A, Pandolf K. 1998). This index is a simple yet effective way to assess heat strain in the lab across multiple types of environmental and activity conditions (Moran, D Shitzer, A, Pandolf, K 1998; Cuddy J, Buller M, Hailes W, Ruby B. 2013; Buller M, Latzka W, Yokota M, Tharion W, Moran D. 2008). To use the scale an individual's resting and current, heart rates and core temperatures are used to calculate a 0-10 score of heat strain (Moran D, Shitzer A, Pandolf K. 1998). Suggested heat strain levels for a moderate PSI are 4-6 while PSI >7 have been found to be high (Moran D, Shitzer A, Pandolf K. 1998). In a study by Buller *et al.* (2008) an occupational risk level was determined to be a PSI>7.5 based on it lies between the high (PSI=7) and very high (PSI=8) levels of PSI. It was found that a PSI of 7.5 could accurately predict individuals "At Risk" of heat strain and only have a 9.9% error rate. A study by Cuddy *et al.* (2013) confirmed the 7.5 thresholds ability to predict individuals "At Risk" for hyperthermia with minimal error for fit and unfit individuals. They also found that fit individuals typically had lower PSI scores compared to their unfit counterparts.

Marksmanship Performance

Cold

The effects of a cold environment and the decreased core, skin, and hand temperatures that can result from cold exposure have had limited effect on shooting performance. In a series of studies that progressively dropped core temperature up to 1ºC, skin temperatures to 24ºC, and finger temps as low at 10ºC found no effect to slight improvements in accuracy (Lakie *et al.* 1995, Tikuisis *et al.* 2002, Reading *et al.* 1984, Tikuisis & Keefe 2007, Adams *et al.* 2007). It has also been seen that the combined effects of cold stress and a 3% dehydration did not affect marksmanship performance at rest (Adams *et al.* 2007). Previous works claim that the slight decrease in core temperature < 1ºC may act as a stimulus and promote increased awareness and focus (Reading *et al.* 1984, Lakie *et al.* 1995, Tikuisis *et al.* 2002). They also claim that at the moment of the shot subjects suppressed the shivering response in order to maintain accuracy. One study did find that at a core temp of 36.3ºC subjects had a decreased target identification time, but accuracy did not decrease further than the target not seen (Tikuisis 2007). They also found a slower aiming time with an increase in range of the target (Tikuisis 2007). It seems that at non-hypothermic levels of cold stress marksmanship performance is not decreased but target identification and shooting times may slow.

Altitude

Altitude has been found to change shooting performance with both acute and chronic exposures. With acute exposure to altitude there is a decrease in shooting accuracy in both the horizontal and vertical directions, a decrease in precision, and a decrease in aiming time (Tharion 1992, Moore *et al.* 2013). While with chronic exposure to altitudes shooting performance improved back to sea level conditions (Tharion 1992). In hypoxia looking at simulated altitude gain at 1000m, 2000m, 3000m, 4000m found that a critical altitude of 3000m was needed to induce a decrease in shooting performance (Moore *et al.* 2013). This study found that the decrease was even larger when progressing to 4000m (Moore *et al.* 2013). This effect is supported by Tharion *et al.* who's attitude was 4300m on the top of Pike's Peak after strenuous exercise and chronic exposure. Previous research therefore, suggests that acute altitude exposure has a negative effect on marksmanship accuracy with acute exposures above 3000m with chronic stay improving performance.

Load

Load carriage effects of marksmanship has previously been researched and has conflicting results based on load intensity, exercise conditions, and peripheral neural side effects of load carriage systems. A study by Tenan *et al.* found when using well trained soldiers and using live fire ammunition soldiers did not have a decrease in shooting performance despite being loaded with a 48.5 Kg rucksack at low intensity exercise (2016). While in other studies using loads as light as 10Kg have been seen to exert a 27% decrease in shot placement. Reasons for these conflicting results may be due to different exercise intensities and length, while also looking at pack quality and fit. It has been reported that load carriage systems that do not fit can cause neural determents in the arms due to the system exerting pressure on the shoulder plexus points (Hadid A, *et al.* 2017). In this study they examined the effects of a 40% BW load carried for 45 minutes and saw that blood flow, touch sensation, but not thermal sensation in the hand was diminished. Marksmanship accuracy was still diminished by 30% after 15 minutes of recovery from the load. Previous work looking at 200-400m sprints with loads on saw a 17-18% decrease in accuracy (Swain *et al.* 2011, Moore *et al.* 2014). Based on these results it seems that the greater the intensity exercise that is performed with a load carriage system the greater the effect on shooting performance. While with load intensity it seems that as long a load weight lighter than 40% body weight is carried negative effects should be avoided at low exercise intensities.

Heat

Previous heat research is limited and difficult to compare due to different methods and marksmanship scoring systems. Light to moderate passive heat stress (core temp 38.2 ºC) has been shown to not effect shooting performance when shooting from a supported prone position (Tikuisis 2002). Another, study by Tikuisis and Keefe (2005) subjects in a hot euhydrated exercise condition reached a moderate to high PSI of 6 but didn’t have any change in accuracy but did have decreased target discrimination. The same study also examined a dehydrated trial where subject reached a PSI of 7 “Not at Risk” with 3.27 % body weight loss, and still had no decreases in accuracy but still had decreased target discrimination (Buller *et al.* 2008, Cuddy *et al.* 2013). This study is difficult to compare to other because their accuracy measure was based on a 1.14m x .45m target hit/miss criteria (Tikuisis 2002, Tikuisis & Keefe 2005). Other studies used actual distance from center of target (Johnson Kobrick 1997, Tharion, 1992, Tharion 1989, Tikuisis 2002). The last two heat studies examine the effects of heat, exercise, and chemical protective clothing which leads to substantial decreases in shooting performance. In Tharion 1989 it was found that the greater dehydrated group (sweat rate >.254%BWL/hr for 6 hours with < 68% rehydration) shot worse than those less dehydrated and those with better rehydration levels. In another study that had subjects exercise in the heat (35 ºC) and ambient temperature (12.8 ºC) for 2hrs in a chemical protective suit saw a decreased accuracy by 26% (Johnson and Kobrick 1997). No other physiological values for heat stress where provided (Johnson and Kobrick 1997). Overall it seems that heat has no effect when at rest or exercise until you add factors such a chemical protective clothing with directly hinder body mobility (Johnson and Kobrick 1997). This could be due to the physical hindrance of the suit or possibly the decreased skin to core gradient (Tikuisus 2005, Cuddy, Hailes, Ruby 2014).

Dehydration, a common side effect of heat exposure, under resting or normal shooting conditions shows no effect. It has been seen even with significant levels of dehydration >3% BW loss that there is no decrease in shooting performance (Tikuisis 2005, Adams *et al.* 2007). But it was seen in both study's that target detection time increased as a result of the dehydration levels regardless of a hot or cold environment. While subjects did see a decrease with moderate dehydration levels in Tharion *et al.* it was likely due the chemical protective suit not dehydration alone (1992).

Exercise

The effect of exercise on shooting performance is conflicting and seems to depend on intensity of the exercise being performed. Low intensity exercise such as walking independent of any other variables in the studies produced no effect on shooting performance (Tenan *et al.*, Tikuisis 2002, Laaksonen *et al.* 2018). While as work rate approach max values we start to see decreases in shooting performance (Laaksonen *et al.* 2018). In a few studies examining sprinting effects on marksmanship it was seen to have an 17-18% decreases in accuracy attributed to exercise (Swain *et al.*, Moore *et al.*). In a study examining prolonged hill climbing it was demonstrated that horizontal deviation of accuracy was affected while vertical deviation was not decreased (Tharion et al 1992). In the same study it was seen that precision in both horizontal and vertical directions increased over rest. It has been proposed in biathletes that the decreases in shooting performance during exercise can be attributed to the increased movement of the chest due to the increased ventilation and heart rate (Laaksonen *et al.* 2018, Hoffman *et al.* 1992). Other suggested methods of decrease by Hoffman *et al.* are that fatigue can also alter postural stability therein decreasing rifle performance (1992). Based on these results and studies it seems that high intensity exercise or fatiguing bouts can lead to a decreased shooting performance but at a lower submaximal intensity shooting performance is not diminished.

Position

The effects of body position have previously been examined in the prone and standing position with both military and biathlete subjects. When using the prone position shooting performance seems to be the highest (Hoffman *et al.* 1992, Tharion et al 1997). This has been suggested because of the high surface area with the ground and high rifle stability. High intensity exercise has been shown to cause some changes in prone shooting mechanics due to the increased movement of the chest because of elevated HR and ventilation (Tharion et al 1997, Hoffman *et al.* 1992) While in the standing position it has been found that this increased heart rate and ventilation does not effect shooting as much as in the prone position (Laaksonen et al 2018). It has been found that in the standing position that postural sway and the ability to limit it, is the primary determinate of shooting performance (Laaksonen et al 2018). This was seen to improve with training and experience in biathletes (Sattlecker G. *et al.* 2014). This could also possibly explain why military subjects show little deviation in shooting performance despite undergoing stressful situations.

Chapter Three: Methodology

Participants

Eight recreationally active veterans were recruited from the University of Montana and the surrounding community, ranging from 18-40 years of age. Subjects completed a Physical Activity Readiness-Questionnaire (PAR-Q) and signed an informed consent form approved by the Institutional Review Board of the University of Montana. Subjects had previously passed a military branches marksmanship qualifications test prior to the study. All subjects were given a detailed explanation of the experimental procedures, expectations of subjects participating in this study, as well as any risks that they may incur as a result of participating in the study.

Preliminary testing

Physical Activity Readiness-Questionnaire (PAR-Q)

A PAR-Q was used to identify whether or not subjects were physically capable of performing the exercise tasks that was asked of the subjects in this study.

Maximal Aerobic capacity (VO_{2max})

Maximal aerobic capacity was determined for each subject in the first visit to the lab after the first shooting assessment and practice. VO_{2max} was determined by using the Bruce protocol (Bruce, Kusumi, & Hosmer 1973). Subjects were at least three hours fasted prior to arriving at the lab for testing. Testing was done on a motorized treadmill (Fullvision, Inc, Newton, KS). Expired gases were captured and analyzed using a metabolic cart every 15 seconds (Parvomedics, Inc., Sandy UT). Heart rate was recorded using heart rate strap and watch (Polar Electro, Kemple, FL).

The Bruce protocol stages are as follows:

Stage 1: 45.5m/min at 10% grade
Stage 2: 67.0 m/min at 12% grade
Stage 3: 91.2 m/min at 14% grade
Stage 4: 112.5 m/min at 16% grade
Stage 5:134.1 m/min at 18% grade

Stage 6:147.5m/min at 20% grade

A subject must have met two of the following criteria to qualify as meeting their VO_{2max}

1. There was a plateau in oxygen consumption despite an increase in workload based on a 15 second interval.

2. The subject's RER was greater than 1.10.

3. The subjects HR was within 10 beats of the participant's predicted max HR.

4. The subject experienced volitional fatigue and reported an RPE of greater than 17.

Body Composition

Body composition was determined for each subject after they had completed their VO2max testing on the first visit to the lab. This was done by hydrodensiometry and estimates of residual lung volume based on their height and weight (Boren *et al.* 1966). Subjects were at least three hours fasted prior to testing. Height was measured, and dry weights were collected prior to entering the water tank using a scale (Befour Inc, Cedarburg WI). Subjects were instructed to expel as much air as possible while fully submerging under water and seated on the weighing platform. Net underwater weights were recorded using load cells (Exertech, Dresbach, MN). Subjects were weighed multiple times until measures within 0.1 kg were obtained to ensure a reliable measure was recorded. The Siri equation was used to calculate body density as well as percent body fat (Siri,1993).

The body density equation used is below. M_a- mass of subject in air collected before entering pool, M_w-Mass collected by load cells with subject submerged, D_w- is the density of the water at the current temperature when weighing, RV- the estimated residual volume calculated using Boren *et al.* 1966, V_{GI}-Volume of aim in the gastrointestinal tract normally 100mL.

$$\text{Density} = M / V = M_A / \{[(M_A - M_W)/ D_W] - RV - V_{GI}\}$$

Siri equation: Body density was taken from the equation above.

$$\% \text{ Body Fat} = (495 / \text{Body Density}) - 450$$

Shooting pre-tests

During the pre-visit subjects were allowed to practice to become familiar with the rifle, (Airoft

M-4, G&G GR15 Raider XL Electric Blowback AEG Shengang Township, Taiwan), shooting system (Noptel Expert Range Optical Targeting System, Oulu, Finland), and the positions that they were asked to shoot from. Subjects were allowed as much shooting practice during the first visit as they feel they needed. After practicing subjects performed a baseline test of three sets of three shots from each position. The shooting positions were counter balanced between subject but held constant within subject for all assessments after the first. These were used later in conjunction with their pre-intervention shooting tests to determine baseline variability in accuracy, precision, time between shots, and distance travelled by point of aim.

The shooting scenario was set up as follows for the shooting pre-test and experimental trails on subsequent visits. They stood, kneeled, or laid with the forward most point of ground contact being on a marker that indicated the 10 m from target. Subjects were reminded and coached on the three shooting positions and were allowed to use their dominant side as it would yield their best results (Jones, F 1996). On the barrel of the air soft rifle was the laser emitting unit from the optical targeting system which interacted with the rifle's recoil mechanisms and the reflective target 10m in front of them in order to track shot placement. This laser unit was hard wired to a computer that had the Noptel software downloaded on it and tracked shot placement throughout the shooting trials. The aim point of the laser unit and sights for each shooter was digitally zeroed each time they entered the lab but not between rounds. This was done from a supported position as to eliminate as much human error as possible. They then performed the shooting task either practice or the assessment depending on which lab visit it was.

Experimental Testing (Lab visits 3 and 4)

Subjects were scheduled for two experimental trials each separated by at least two weeks to prevent heat acclimation effects that may have influenced performance results (Hailes, Cuddy, Cochrane & Ruby, 2016). Subjects were asked to maintain a food and activity log 24 hours prior to arriving at the lab for the first trial, and to replicate the log 24 hours before the second visit. Subjects arrived at the lab at least eight hours fasted prior to testing.

The subjects underwent the following prior to each exercise trial: In private, each subject had nude body weight measured (Befour Inc, Cedarburg WI), self-inserted a core temperature probe, approximately 12 cm past the anal sphincter (Physitemp, Clifton, New Jersey), and dressed in personal undergarments and provided standard issue Air Force Battle Dress Uniforms pants and shirt. Once dressed each subject put on a heart rate chest strap and watch (Polar Elector, Kemple, FL, USA) and connected temperature probe to a data logger (USB 500, Measurement Computing, Norton, MA, USA). Finally, the rifle was sized and zeroed before completing the pre-exercise rested shooting assessment. Subjects then proceeded to the climate chamber for their hour of exercise in the hot or cool intervention. The order of the interventions was counter balanced between subjects.

Cool Exercise Intervention

In the cool trial, subjects entered the climate chamber that was approximately 22º C and 30% maximal relative humidity. Subjects walked on a treadmill at 93.8 m/min and grade that was equivalent to 50% of the predetermined VO2max for 1 hour. Subjects were then immediately taken to the shooting scenario to complete the shooting tasks. Core temperature and heart rate were recorded every 15 minutes during the exercise bout.

Hot Exercise Intervention

In the heated trial, subjects entered the climate chamber that was set to 35.5 º C and 30% maximal relative humidity. Subjects walked on a treadmill ergometer at 93.8m/min and grade that was equivalent to 50% of their predetermined VO2max for 1 hour. Subjects then were immediately taken to the shooting scenario to complete the shooting task. Core temperature and heart rate were recorded every 15 minutes during the exercise bout.

Post-Exercise Shooting Protocol

After completing the exercise intervention subjects immediately entered the shooting scenario and began the shooting assessment of three groups of three shots for each position. Shooting data was collected by the optical targeting system and stored for later analysis. After shooting the assessment the post nude body weight was collected using a scale (Befour Inc, Cedarburg WI)

Measurements

Shooting Parameters

The data collected was accuracy, horizontal deviation, vertical deviation, precision, time between shots, and distance travelled by the point of aim. Accuracy was collected as an ordered 2D x-y pair (x-horizontal, y- vertical) in millimeters from the center of the target that each shot was placed by the shooter (Noptel). The straight-line distance that each shot was placed from center (accuracy) was calculated using the horizontal and vertical deviations from center. Horizontal and vertical deviations are the absolute values the distance from center in their respective directions. Precision was calculated by using the centroid method for each group of shots placed. The furthest shot from the centroid was used to establish the diameter of the circle to enclose all three shots per group. Time between shots was collected directly from the optical targeting system for each shot after the first shot has been taken in seconds (Noptel). These two-time points were averaged for each group. Distance travelled was collected as the change in position between each collection point (77Hz), a continual summation was used to determine the total distance travelled in millimeters between each shot taken (Noptel). This distance was averaged for a group total. Each of the three-group data points for all variables were then averaged into a position average so it could be compared between conditions and baseline variability

Temperature

Core temperature was monitored continuously on a digital data logger throughout the exercise and shooting protocols. Core temperature was recorded at the beginning and every 15 minutes during exercise bouts. All other times it was monitored for the safety of the subject.

Heart Rate

Heart rate was monitored continuously on a Polar heart rate watch throughout exercise and shooting protocols. Heart rate data was recorded at the beginning and every 15 minutes throughout exercise bouts. All other times it was monitored for the safety of the subject.

Percent Body Weight Loss

Nude body weight was taken at the beginning of the intervention visits before pre-exercise shooting assessment and then again after the completion of the post-exercise shooting assessment. Percent loss of body weight was calculated over the one hour of exercise.

$$\text{\% body weight loss} = \text{Body weight}_{pre}/\text{Body weight}_{post}$$

Physiological Strain Index (PSI)

PSI was calculated using the core temperatures and heart rates collected at the 0, 15, 30, 45, and 60-minute collection times. It was calculated using the Moran, D *et al.* 1998 methods, equation below. Tre_t and HR_t are the core temperature and heart rates collected at times 0, 15, 45, and 60. Tre_0 and HR_0 are the resting core temperature and heart rate collected at time 0.

$$PSI = 5(Tre_t - Tre_0) / (39.5 - Tre_0) + 5(HR_t - HR_0) / (180 - HR_0)$$

Statistical Procedures

All values were reported as mean ± SD. Data was considered significant with a 95% confidence interval ($p<0.05$). Analysis was performed using Microsoft Excel Software and SPSS version 23.

Percent body weight loss values, calculated from the pre and post exercise nude body weights, were analyzed using a paired students t-test between the hot and cool trials. The physiological values of core temperature, heart rate, and PSI were analyzed using a 2-factor [2(condition) x 5(time)] repeated measures ANOVA. The 2 levels of condition were the hot and cool exercise trials and the five levels of time (0, 15, 30, 45, and 60-minute measurements).

All shooting measurements were initially compared with a within-subject repeated measured ANOVA for time. The four resting shooting assessments are; two from the pre-trials visit assessments and the two resting pre-exercise assessments. These were put in-order of completion regardless of the exercise condition to follow. All shooting measures were also compared using a 2-factor [3(condition) x 3(position)] repeated measures ANOVA. The three conditions were the hot post-exercise assessment, cool post-exercise assessment, and resting pre-exercise assessment. The resting pre-exercise assessment is an average of the two pre-exercise assessments. A Least Significant Difference (LSD) test was used for post-hoc analyses where significant differences were found ($P<0.05$).

Chapter 4: Manuscript

Research Article

EFFECTS OF HEAT STRESS AND EXERCISE ON SHOOTING PERFORMANCE

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Abstract

Purpose: The purpose of this study was to evaluate the effects of exercise and acute heat stress on marksmanship performance measures of accuracy, precision, aim time, and distance travelled by the point of aim in trained US military veterans. **Methods:** Subjects (*N*=8) (height 184.1 ± 10.9 cm (SD), weight 92.1 ± 10.6 kg, 21.1 ± 8.9% body fat, VO_{2max} 47.25 ± 7.36 mL/kg/min, age 26.8 ± 4.3 yrs.) completed one-hour of walking at 50% VO_{2max} in a hot (35˚C, 30% maximal relative humidity) or cool (22˚C, 30% maximal relative humidity) environment. Core temperature, heart rate (HR), and physiological strain index (PSI) were recorded throughout the exercise period. Shooting assessments and nude body weights were completed before and after exercise to determine % body weight loss, accuracy, horizontal and vertical deviation, precision, aim time, and distance travelled by the point of aim. **Results:** Core temperature, HR, and PSI increased from rest (35.7 ± 4˚C; 88 ± 4bpm) in both cool (37.8 ± .5˚C; 143 ± 20bpm, 5.5 ±1.6) and hot (38.5 ± .4˚C; 167 ± 13 bpm, 7.8 ±1.11) conditions at 60 minutes but were significantly greater in hot compared to cool in the latter half of the trial. Percent body weight loss was greater in the hot (1.5 ± 0.5 %) compared to cool (0.9 ± 0.5 %). Aim time decreased for cool (3.2 ± 0.4 sec SE) and hot (2.9 ±0.3 sec SE) trials compared to rest (4.1 ± 0.4 sec SE). Vertical deviation increased in the kneeling position (10.7 ± 0.7 mm SE) compared to prone (15.3 ± 1.3 mm SE) or standing (14.1 ± 1.2 mm SE). There were no changes from rest for accuracy, distance travelled, or precision in either hot or cool trials. **Conclusion:** Despite elevated levels of physiological strain there were no decrements in marksmanship performance due to exercise or heat stress. Kneeling may alter vertical deviation more than prone or standing shooting positions during marksmanship tasks. These data also indicate a need for more work related to prolonged, elevated PSI and/or % body weight losses commensurate with or exceeding the suggested 2% criteria.

Keywords: Marksmanship, Heat stress, Military, Exercise

Intro

Moderate to high heat stress is known to cause significant decreases in both physical and cognitive function leading to decreased performance in recreational and occupational athletes (6,13,22). For military service members, hot environments and necessary protective clothing/gear contribute to the risk of overall heat stress (13). The associated decreases in physical and cognitive function can lead to a decrease in work output, vigilance, and marksmanship performance (13,22). While all decreases in performance are undesired, a decrease in marksmanship performance can directly impact the effectiveness, safety, and possible survival of a service member.

Marksmen are often assessed on their ability to hit the center of a target (accuracy) and control the spread of consecutive shots (precision) (18). These skills require extensive amounts of physical and cognitive training to develop consistent performance capabilities regardless of external stimuli. Biathlete marksmen are more accurate and precise compared to novice controls, due to pronounced marksmanship training (12). Reasons for this increase in performance with experience has been attributed to better fitness, postural control, trigger pull, and motor control over the process of shooting actions (8,12). Although exercise and fatigue has been demonstrated to decrease marksmanship in biathletes, advanced training experience can attenuate expected decrements (12). However, it is unclear if other disruptions to homeostatic conditions may decrease marksmanship performance.

Previous research examining the interaction between heat stress and marksmanship performance has been limited and shows mixed results. When heat stress is induced via passive methods and supported shooting positions are used, it appears that greater body temperature alone does not change the accuracy or precision (20). While, exercising in a hot environment, using unsupported positions, in chemical protective clothing, and being dehydrated (Percent Body weight loss, % BW loss) decreased accuracy and precision performance were found (19). While subjects that rehydrated >68% of the lost body water had less of a decrease than those who did not rehydrate (19). Previous research has also examined the effect of protective clothing in hot environments and it's confounding effects on marksmanship performance. When subjects were exposed to umcompensible heat stress in protective clothing (67 m/min at 35 ˚C), total targets hit decreased by 26% (11,19). Aiming time has been seen to decrease, resulting in faster shooting rates, in all studies when subjects were exposed to exercise, heat, or exercise and heat combined resulting in overall PSI values equal to 7.1 ± 2.5 and body weight loss >3.27 ± 1.11 (11,19,20). This decrease in aiming time was independent of no change or decrease in accuracy or precision scores.

Military service members are asked to complete a large variety of tasks and jobs around the globe and in every environment that can be occupied. Their physical and cognitive fitness and performance is one of the most important tools that a service member can possess. Heat stress can alter physical and cognitive performance in military member duties possibly increasing risk. Therefore, the purpose of this study was to examine the effects of moderate to high heat stress, exercise, and mild dehydration on measures of shooting accuracy, precision, distance travelled by the point of aim, and aiming time in trained US military veterans.

Methods

Subjects

Eight recreationally active military veterans were recruited from University of Montana and the surrounding community. The study protocol was approved in advance by the Institutional Review Board of University of Montana. Each subject provided written informed consent and

PAR-Q before participating. Each subject previously passed a military branches marksmanship qualifications test to participate in the study.

Protocol

Subjects were asked to attend three lab sessions. The first pre-trial visit included consent, completion of the PAR-Q, VO_{2max} testing, body composition testing, shooting familiarization, and two shooting assessments. The remaining two visits were experimental trials to investigate marksmanship performance in response to a hot (35.5º C, 30% relative humidity) and cool (22º C and 30% relative humidity) exercise condition. These trials were counterbalanced for both environmental condition and shooting position order between subjects.

Pre-Trial Visit

In the pre-trial visit subjects were first allowed to practice and familiarize themselves with the rifle and optical targeting system before completing any recorded shooting. They then completed their first rested shooting assessment before completing the VO_{2max} and body composition testing. Subjects went until volitional termination using a Bruce treadmill protocol to establish their VO_{2max} (3). A metabolic cart collected and analyzed expired gases every 15 seconds during the test (Parvomedic Inc., Sandy, UT). Heart rate was recorded using a heart rate strap and watch (Polar Electro, Kemple, FL). A subject must have met two of the following criteria to qualify as meeting their VO_{2max}, 1) There is a plateau in oxygen consumption despite an increase in workload based on a 15 second interval. 2) The subject's RER is greater than 1.10. 3) The subjects HR is within 10 beats of the participant's predicted max HR. 4) The subject experiences volitional fatigue and reports an RPE of greater than 17.

Body composition was determined for each subject after they had completed their VO_{2max} testing. This was done using hydrodensiometry and estimates of residual lung volume based on their height and weight (2). Underwater weights were recorded using load cells (Exertech, Dresbach, MN) to compute body density. Percent body fat was calculated from body density using the Siri equation (16). Subjects then returned to the shooting scenario to complete their second rested shooting assessment.

Experimental Visits

Subjects were scheduled for two experimental trials each separated by at least two weeks to prevent heat acclimation effects that may have influenced performance results (7). Subjects were asked to maintain a food and activity log 24 hours prior to arriving at the lab for the first trial, and to replicate the log 24 hours before the second visit. Subjects arrived at the lab at least eight hours fasted prior to testing.

The subjects underwent the following prior to each exercise trial: In private, each subject had nude body weight measured (Befour Inc, Cedarburg WI), self-inserted a rectal temperature probe, approximately 12 cm past the anal sphincter (Physitemp, Clifton, New Jersey), and dressed in personal undergarments and provided standard issue Air Force Battle Dress Uniforms pants and shirt. Once dressed each subject put on a heart rate chest strap and watch (Polar Elector, Kemple, FL, USA) and connected the rectal temperature probe to data logger (USB 500, Measurement Computing, Norton, MA, USA). Finally, the rifle was sized and zeroed before completing the pre-exercise rested shooting assessment.

The subjects entered a climate chamber for both trials to begin the exercise intervention. The exercise intervention for both conditions included walking on a treadmill at 93.8 m/min and a grade adjusted to a workload equivalent to 50% of their predetermined VO_{2max} for one hour. In the cool trial the chamber was kept at temperature of 22º C and 30% maximal relative humidity. In the hot trial the chamber was set to 35.5º C and 30% maximal relative humidity. Core temperature and heart rate were continuously collected but isolated at time points; 0, 15, 30, 45, and 60 minutes for analyses. Upon completing the one-hour exercise intervention participants immediately exited the chamber and completed the post-exercise shooting assessment. After completing the shooting assessment, a post-exercise nude body weight was collected (Befour Inc, Cedarburg WI).

Shooting Assessments

All shooting assessments were done using a weight matched air soft rifle (Airsoft M-4, G&G GR15 Raider XL Electric Blowback AEG Shengang Township, Taiwan), and optical targeting system (Noptel Expert Range Optical Targeting System, Oulu, Finland). All lab visits began with sizing the rifle for the subject and zeroing the optical targeting system with the rifle sights. All assessments recorded consisted of three sets of three shots from each of the three shooting positions: prone, kneeling, and standing. Subjects could lower and rest the rifle between sets but not between shots within the set.

The shooting scenario was set up as follows for the shooting assessments during the pre-test visit and experimental trails. Subjects stood, kneeled, or laid prone with the forward most point of ground contact being on a marker that indicated 10m from the target. The target was directly in front of the subject with no viewing obstructions and good lighting. Subjects were reminded and coached on the three shooting positions and were allowed to use their dominant side as it would yield their best results (10). Mounted on the underside barrel of the rifle was the laser-emitting unit from the optical targeting system which interacted with the rifle's recoil mechanisms and the reflective target 10 m in front of them to track shot placement. This laser unit was hard wired to a computer that had the Noptel software downloaded on it and tracked shot placement throughout the shooting trials. The aim point of the laser unit and sights for each shooter was digitally zeroed each time they entered the lab but not between rounds. This was done from a supported position as to eliminate as much human error as possible. They then performed the shooting task either practice or the assessment.

The data collected was accuracy, horizontal deviation, vertical deviation, precision, time between shots, and distance travelled by the point of aim. Accuracy was collected as an ordered 2D x-y pair (x-horizontal, y- vertical) in millimeters from the center of the target that each shot was placed by the shooter. The straight-line distance that each shot was placed from center (accuracy) was calculated using the horizontal and vertical deviations from center. Horizontal and vertical deviations are the absolute values of the distance from center that each shot was placed in their respective directions. Precision was calculated by using the centroid method for each group of shots placed. The furthest shot from the centroid was used to establish the diameter of the circle to enclose all three shots per group. Time between shots was collected directly from the optical targeting system for each shot after the first shot has been taken in seconds. These two-time points were averaged for each group. Distance travelled was collected as the change in position between each sampling point (77Hz), a continual summation was used to determine the total distance travelled in millimeters between each shot taken. This distance was averaged for a group total. Each of the three-group data points for all variables were then averaged into a position average so it could be compared between conditions and baseline.

Physiological strain index was calculated for each of the heart rate and core temperature measurements points during both cool and hot trials (13).

$$PSI = 5(Tre_t - Tre_0) / (39.5 - Tre_0) + 5(HR_t - HR_0) / (180 - HR_0)$$

Tre_t and HR_t represent the core temperature and heart rate values collected at times 0, 15, 45, and 60 during each exercise trial. Tre_0 and HR_0 are identified as the resting core temperature and heart rate collected at time 0. We used a PSI > 7.5 to classify high heat strain "At Risk" and <7.5 for moderate heat strain "Not at Risk" as previously identified (4,5).

Statistical Procedures

Percent body weight loss values, calculated from the pre and post exercise nude body weights, were analyzed using a paired students t-test between the hot and cool trials. The physiological values of core temperature, heart rate, and PSI were analyzed using a 2-factor [2(condition) x 5(time)] repeated measures ANOVA. The 2 levels of condition were the hot and cool exercise trials and the five levels of time (0, 15, 30, 45, and 60-minute measurements).

All shooting measurements were initially compared with a within-subject repeated measured ANOVA for time. The four resting shooting assessments included, two from the pre-trials visit assessments and the two resting pre-exercise assessments. These were put in-order of completion regardless of the exercise condition to follow. All shooting measures were also compared using a 2-factor [3(condition) x 3(position)] repeated measures ANOVA. The three conditions were the hot post-exercise assessment, cool post-exercise assessment, and resting pre-exercise assessment. The resting pre-exercise assessment is an average of the two pre-exercise assessments on experimental visits.

Data was considered significant with a 95% confidence interval. A Least Significant Difference (LSD) test was used for post-hoc analyses where significant differences were found ($P<0.05$). Unless otherwise stated all reported values are expressed as mean ± SD.

Results

Eight participants (height 184.1 ± 10.9 cm, weight 92.1 ± 10.6 Kg, 21.1 ± 8.9 % body fat, VO_{2max} 47.25 ± 7.36 mL/Kg/min, age 26.8 ± 4.3 yrs.) completed all pre-trials and experimental visits.

The time x trial interaction was significant for the measure of core temperature (P=0.022) (Figure 1). Core temperature was significantly elevated above rest for time points 15, 30, 45, and 60 minutes for the cool trial (P<0.05). The hot trial demonstrated a significantly elevated core temperature from rest at time points 30, 45, and 60 minutes (P<0.05). Core temperature was significantly greater at the 45 and 60 minutes during the hot trial compared to the cold (P=0.008, P=0.012 respectively).

The time x trial interaction was significant for heart rate (P<.001) (Figure 2). At all measurement points 15, 30, 45, and 60 minutes, HR values were higher than rest regardless of hot (P<0.001) or cool trials (P< 0.002). Heart rate was significantly higher during the hot trial at the 30, 45, and 60 minutes measurement compared to the cool trial (P=0.035, P=0.004, P=0.002).

The time x trial interaction was significant for PSI (P<0.001) (Figure 3). At all measurement points 15, 30, 45, and 60 minutes PSI values were higher than rest in both cool and hot trials (P<0.001). PSI was significantly higher at the 45- and 60-minute measurements for the hot trial than the cool (P=0.006 and P=0.002). During the cool trial, average PSI did not exceed 7.5 and reached a mean peak value of 5.5 ± 1.63. However, during the hot trial average peak PSI was 7.8 ±1.11 at 60 minutes.

Percent body weight loss was higher in the hot trial (1.5 ± 0.5 %) compared to the cool trial (0.9 ± 0.5 %, P=0.03).

There was a learning effect detected for aiming time across the four resting shooting assessments (*P*=0.021). Assessments three and four where significantly longer than one and two (Table I). However, three and four (dedicated experimental trials cool and hot) were not significantly different from each other (*P*=0.241). The main effect for trial was significant (*P*=*0*.003) for the measure of aim time between shots (Figure 4). Both the cold (*P*=0.005) and hot (*P*=0.004) trials had significantly lower aiming times compared to resting. There was no difference between the cold and hot trials for aiming time(*P*=0.459)

There was no learning effect detected in the vertical deviation (*P*=*0*.138) (Table I). There was a significant main effect of position on the vertical deviation in shooting trials (*P*=0.019) (Figure 5). There was a greater vertical deviation in the kneeling position when compared to prone (*P*=0.027) but standing was not different from prone (*P*=0.055) or kneeling (*P*=0.358) positions (Figure 5). There was a learning effect observed in the horizontal deviation measurement between the four pre-trial shooting assessments (*P*=0.02) (Table I). It was seen that the fourth visit had less deviation than visits one and two (*P*=.021, *P*=0.017) there was no further changed between visits three and four the experimental trials (P=0.097). The main effect for trial was significant (P<0.017). Horizontal deviation significantly increased from rest (13.7 ± 1.5 mm *SE*) after exercise in the hot (19.0 ± 1.7mm *SE*, P<0.020) but not the cool (15.3 ± 1.4 mm *SE*, P=0.209) environments. There was no difference in horizontal deviation between hot and cool trials (P=0.090)

There was no learning effect detected across the study for accuracy across the three visits for the study (P=0.629) (Table 1). The was no difference in accuracy in the hot (prone 26.5 ± 7.9 mm, kneeling 26.6 ± 7.7 mm, standing 20.6 ± 6.4 mm) or cool (prone 18.9 ± 4.6 mm, kneeling 25.9 ± 8.9 mm, standing 24.0 ± 9.5 mm) exercise trials from resting values (prone 20.4 ± 8.2 mm, kneeling 23.9 ± 8.4 mm, standing 24.0 ± 8.9 mm). There was no learning effect across the study for distance travelled between shots (P=0.170) (Table I). There was also no difference in distance travelled between rest (prone 335 ± 142 mm, kneeling 434 ± 135 mm, standing 350 ± 101 mm), cool (prone 337 ± 156 mm, kneeling 340 ± 99 mm, standing 406 ± 140 mm), or hot (prone 475 ± 146 mm, kneeling 508 ± 248 mm, standing 408 ± 175 mm) shooting assessments. There was no learning effect detected across the three lab visits and four resting shooting assessments for precision (P=0.619) (Table I). No difference was observed for precision across the pre-trial (prone 15.4 ± 6.3 mm, kneeling 19.0 ± 6.1 mm, standing 16.5 ± 2.9 mm), cool (prone 11.4 ± 3.9 mm, kneeling 17.5 ± 3.7 mm, standing 16.7 ± 3.0 mm), or hot (prone 14.4 ± 7.5 mm, kneeling 14.7 ± 4.6 mm, standing 13.8 ± 4.8 mm) shooting assessments.

Discussion

The results of this study indicate that during short term moderate to high heat strain, well-trained marksmen show limited signs of decreased shooting performance when hydration status did not drop greater than 2% initial body weight. This is demonstrated by no decreases in measures of shooting accuracy and precision despite reaching a moderate to high PSI score of 7.85 ± 1.11 coupled with a moderate change in percent body weight loss 1.5 ± 0.5 % (6,23). Despite the no change in accuracy measures there was an increased horizontal deviation in our subjects with the heat and exercise. Our subjects did have a decreased aiming time, resulting in a faster rate of fire, after both exercise trials but did not show any difference in performance with heat stress. While time between shots was reduced, the distance between shots on target was unaffected similarly between trials indicating that after exercise the subjects point of aim had a greater velocity after exercise than at rest. The results also showed that shooting performance is unaffected by shooting in the prone and standing positions but may decrease when using a kneeling position regardless of physiological strain.

The findings that accuracy and precision do not change with an acute high heat stress or moderate exercise expands current research findings in non-protective clothing (19,20,21). It has previously been shown that in the prone and standing positions when exposed to light (core temperature rises to 38.1 ± 0.29˚ C) to moderate heat stress (PSI-7.1 ± 2.5) no change in accuracy occurred (20, 21). Our study extends that range to a higher heat strain of PSI >7.5 commensurate with higher heat related injury risk (3,4). However, our trial does not represent extended or prolonged heat stress, as average PSI extended above 7.5 for only the last 15 minutes of exercise (heat trial). It also agrees with Tharion *et al.* 1989 (19) who demonstrated that despite high levels of dehydration >1.5% BW loss no changes in accuracy occurred when in non-protective clothing. Our work also confirms the detrimental effects of chemical protective clothing on human performance beyond that of heat and exercise stress (11,19). In the two studies that examined the effects of chemical protective clothing after heat exposure and exercise it was found marksmanship significantly decreased up to 26% (11,19). While the total heat stress imposed in either study was not presented, in Tharion *et al.* (19) they did show a significant sweat rate (>1.5 %BWL with < 68% rehydration during exercise) after their heat exposure (19). Before our study, direct comparison of Tikuisis & Keefe's (21) high heat stress and those of Johnson and Kubrick's (11) and Tharion *et al.*'s (19) could not be done due to a difference in accuracy measures (21). This was because Tikuisis and Keefe (21) had used a hit or miss condition with the sensitivity of 1.14m x.45m where as in Johnson and Kobrick (11), and Tharion *et al.* (19) measured the distance from the center of the target in millimeters. Our study has now assessed with direct measures of accuracy like Johnson and Kobrick (11) and Tharion *et al.* (19) that heat stress and moderate levels of dehydration (1.5 ± 0.5%) does not impede shooting accuracy and precision. Therefore, the results that demonstrate a decreased shooting performance in chemical protective clothing after a moderate to high heat stress may result from protective clothing-oriented movement impairment and/or prolonged exercise (11,19). In Johnson and Kobrick they found that arm and hand steadiness were decreased with chemical protective clothing when exposed to heat and exercise for two hours (11). They also found that the chemical protective clothing caused a complete termination of testing at 2 hours instead of the planned 6-hour trial (11).

Our findings that light to moderate levels of dehydration do not decrease shooting performance agree with previous marksmanship findings. Tikuisis and Keefe (21) demonstrated that a heat stress eliciting a body weight loss of 3.2 ± 1.1 % BW loss did not decrease accuracy but did decrease target identification percentages. While another in a cold environment that also achieved a >3% body weight loss noted no decrease in shooting accuracy or precision while rested (1). However, it is surprising that with a high heat stress (PSI >7.5) and with significant dehydration (1.5 ± 0.5 %) that no decrease in shooting performance was observed (4,23). This is because it is generally accepted that a body weight loss of 2% or greater due to dehydration can cause significant decreases in human performance (6,23). Prior findings demonstrate that neuromuscular function and postural control decreased significantly after exercise when percent body weight loss exceeded 2% (6). However, additional work has shown significant cognitive and skill decay during simulated driving with even small changes in body weight loss of 1.1±0.7% (23). These decreases in cognitive function and neuromuscular control contradict the reported trends of no change in marksmanship scores (6,23). Because shooting is a complex task that relies on proper vision, cognitive function, and postural control a decrease in performance may be expected (8,9,12). However, this further demonstrates that additional work is needed to elucidate the implications of heat stress and on marksmanship task before and after acute and prolonged exercise exposures.

The lack of a decrease in accuracy due to exercise, heat, or shooting position despite shifts in horizontal and vertical deviations is surprising. Our study observed a greater horizontal deviation with the elevated heat strain in the hot environment when compared to rest or exercise alone. While no other studies directly look at heat and exercises' effect on horizontal deviations it has been seen that after strenuous exercise at altitude that horizontal deviation did increase (17). In their study they did see an associated decrease in accuracy with exercise and altitude, which may indicate that our heat stress was beginning to elicit changes (17). We may not have had our subjects up at temperature long enough or may not have reached the detrimental heat threshold. The increase in horizontal deviation could be tied to the increased average velocity of the point of aim after exercise as seen by our decrease in aim time but consistent distance covered by the point of aim. It is of interest that even with the greater velocity and increased horizontal deviation the marksmen were still able to place accurate shots. The significant increase in vertical deviation in the kneeling position is new to research. Previous studies have only examined standing and prone shooting positions, so the future work is needed to discover the effects of kneeling on marksmanship performance. This data shows that while the point of impact may shift due to exercise or shooting position it does not affect the overall accuracy of well-trained marksmen.

Conclusions

This study suggests that mild dehydration and elevated heat stress (identified as a PSI>7.5) do not negatively affect shooting performance after 60 minutes of moderate physical activity. However, time aiming down sights did decrease and horizontal deviation increased without effecting accuracy and other performance measures. There is no effect of standing or prone positions on shooting performance but there could be an increase in vertical-deviation when kneeling. Military subjects maybe well trained enough to overcome expected decreases in shooting performance that heat, dehydration, and exercise induce. This study indicates that more research needs to be done with heat, exercise, and marksmanship to establish dehydration and PSI thresholds that may negatively alter performance. Also, the impacts of shooting experience, particularly military marksmen, to determine the experience thresholds and their associated benefits because our subjects showed no decrease in performance despite suffering from a high PSI.

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Tables:

Table 1. Shooting variables for the four rested shooting assessments to look for effects of learning across the three lab visits. 1 and 2 were collected at the pre-visits, 3 was the first experimental visit, and 4 was the second experimental visit. * (P<0.05) vs. 1 & 2.

Variable	1	2	3	4
Aim Time (sec)	2.9 ± 0.6	2.6 ± 0.3	4.2 ± 1.1*	4.3 ± 1.4*
Accuracy (mm)	22.7 ± 2.9	25.4 ± 5.1	23.5 ± 5.1	25.8 ± 8.9
Horizontal Deviation (mm)	17.8 ± 3.5	18.4 ± 6.6	14.8 ± 5.8	11.8 ± 4.7*
Vertical Deviation (mm)	10.3 ± 3.9	16.6 ± 5.8	11.7 ± 9.4	18.0 ± 8.3
Precision (mm)	16.4 ± 16.7	16.4 ± 17.1	17.6 ± 18.3	17.3 ± 17.0
Distance Travelled (mm)	323.1 ± 121.5	431.4 ± 156.5	383.4 ± 75.3	396.7 ± 102.1

Figures:

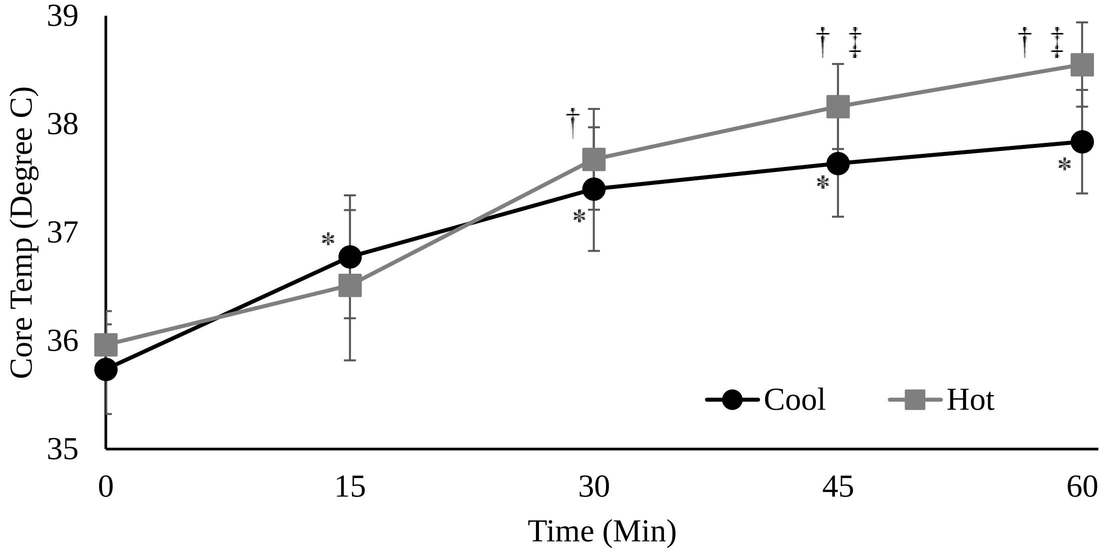

Figure 1. Core temperature response during the 1-hour exercise trial for the hot and cool exercise interventions (*N*=8). Values are mean ± SD. * *P*<.05 vs. rest, †- *P*<.05 vs rest, ‡- *P*< .05 vs cold.

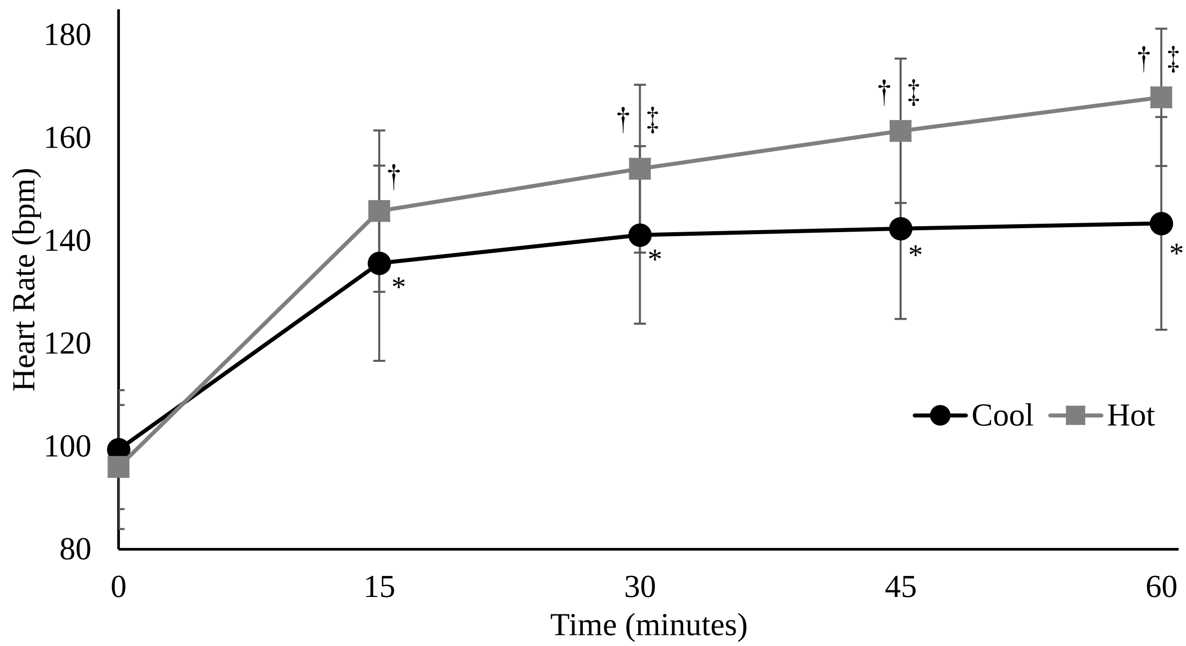

Figure 2. Heart rate response during the 1-hour exercise trial for both hot and cool exercise interventions. (*N*=8), values presented are means ± SD. * *P*<0.05 vs rest, † *P*<0.05 vs rest, ‡ *P*<0.05 vs cold.

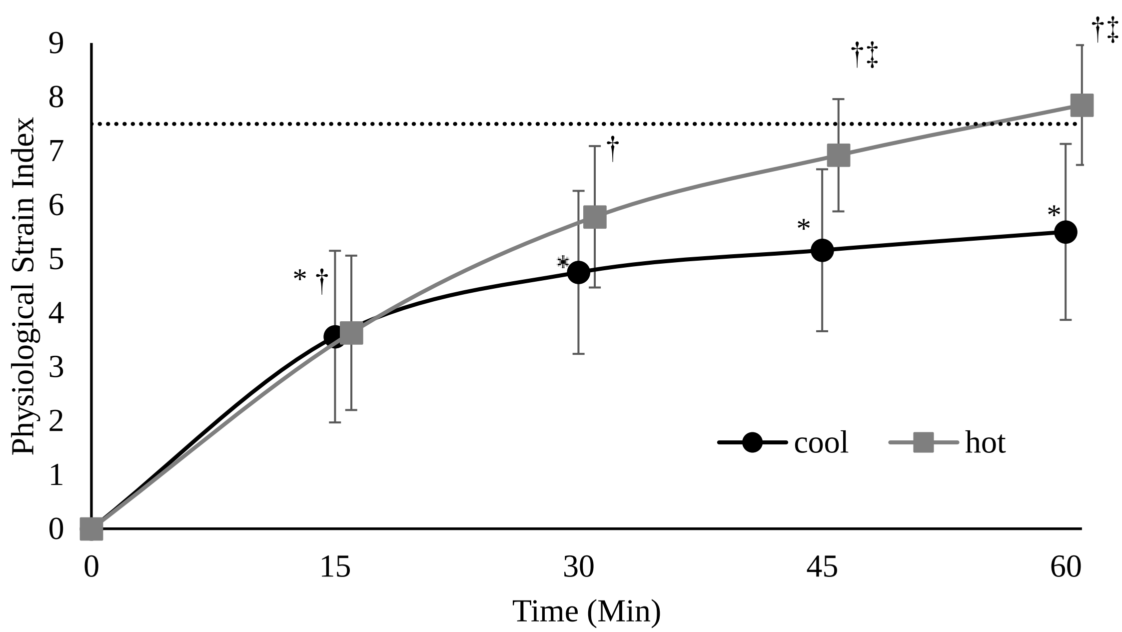

Figure 3. Physiological Strain Indexes response during the 1-hour exercise trial for both hot and cool exercise interventions. Dotted line indicates a PSI of 7.5 a known threshold for heat injury risk. (*N*=8), values presented are means ± SD. * *P*<0.05 vs rest, † *P*<0.05 vs rest, ‡ *P*<0.05 vs cold.

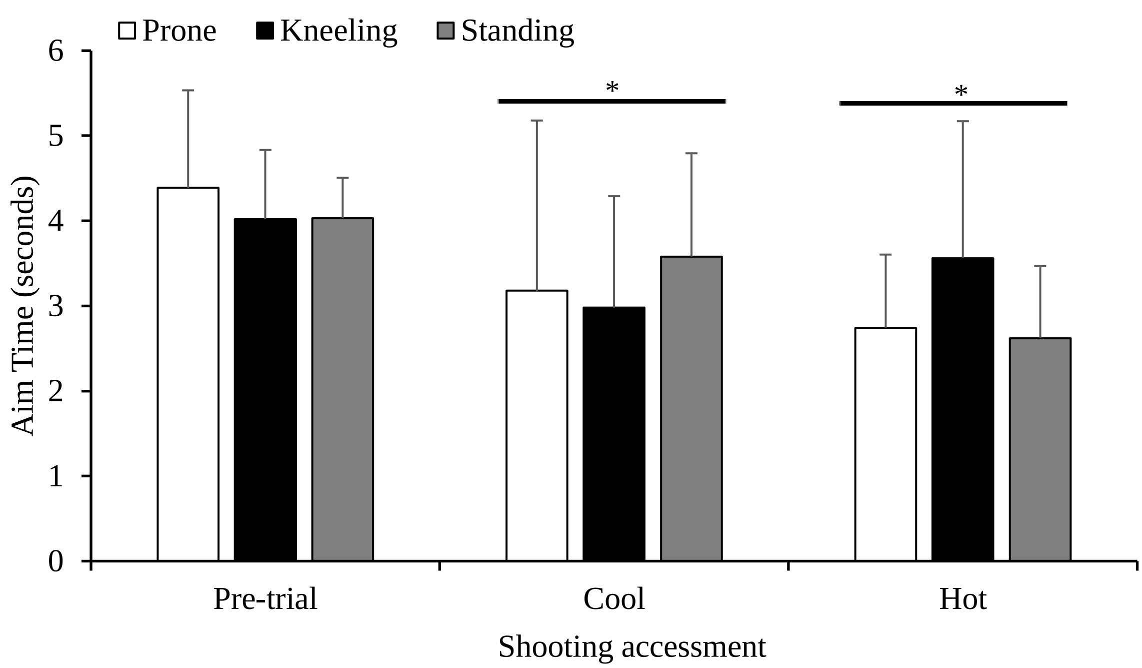

Figure 4. Aiming time between shots for rest, cool, and hot assessments and positional data for each shooting assessment. (*N*=8), values presented are means ± SD. * *P*<0.05 vs Pre-trial assessments.

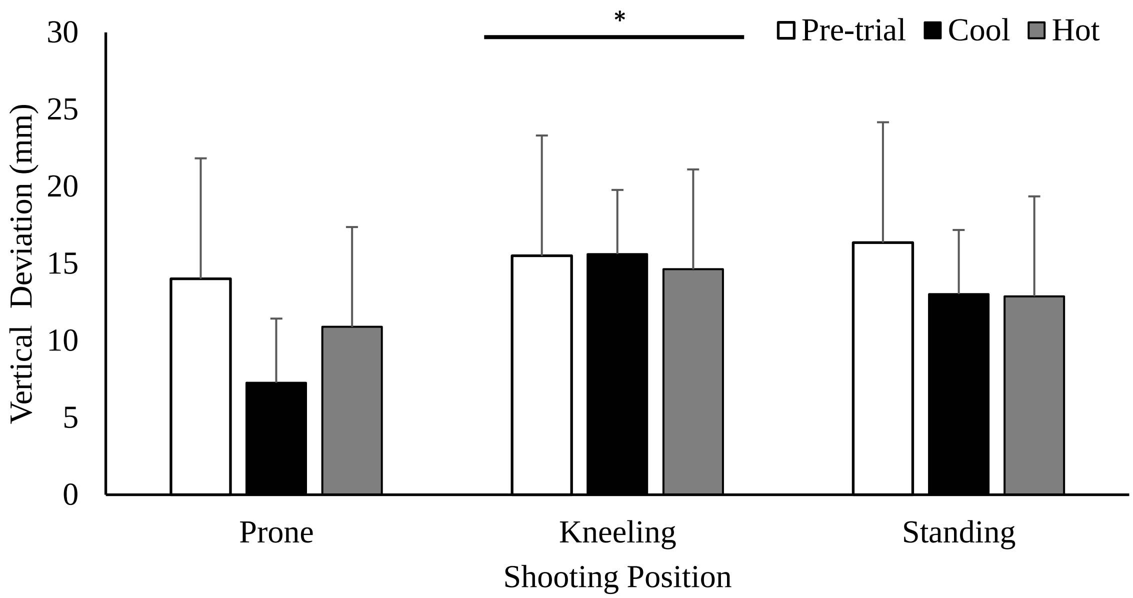

Figure 5. Vertical deviation for the shooting trials by position. Vertical deviation is significantly higher in the kneeling position compared to prone and standing. (*N*=8), values presented are means ± SD. * (*P*= .05) vs prone.

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