MICROENVIRONMENT AND MICROCOOLING
FOR SOFT BODY ARMOR

by

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ABSTRACT

Physical activity in a hot environment has been shown to increase heat storage, which can lead to elevated core body temperature ($T_{re}$). This heat storage is more problematic when an individual is wearing soft body armor (SBA), which inhibits convective and evaporative heat loss. Law enforcement personnel typically depend on Level II SBA for protection, which can be worn concealed or external, covers most of the upper body, and weighs ~3 kg. One way to circumvent excess heat storage is to promote air flow under the SBA. The three purposes of this study were to investigate the cooling effects of adding an ambient air induction system (100 L · min$^{-1}$) and 1.27 cm standoffs in a WBGT = 30 °C environment to: 1) a concealed Level II SBA, 2) an external Level II SBA; and 3) to determine to establish WBGT corrections for concealed Level II SBA at two separate macro-WBGTs (26°C & 30 °C) for a 60 min workload. Counterbalanced, repeated measures protocols were performed with 9 participants (27 ± 4 yr). Each participant performed cycles of 12 min of walking (1.25 L · min$^{-1}$) and 3 min of arm curls (14.3 kg, 0.6 L · min$^{-1}$) with a 5 min rest after the first two cycles for a total of 60 min. During each trial the following variables were recorded every 5 min: $T_{re}$; SBA microclimate (iButtons); heart rate; thermal comfort; and perceived exertion. A repeated measures ANOVA with Bonferroni post hoc analysis was used to evaluate: $T_{re}$, microclimate, heart rate, sweat loss, perceived exertion, and comfort. A mixed model repeated measures ANOVA was conducted on macro-WBGTs and micro-WBGT differences within the three environments to begin to establish WBGT corrections for concealed Level II SBA. Ambient air induction was found to lessen heat strain in concealed Level II SBA but not for external SBA. Further improvements
are necessary to achieve similar results in externally worn SBA. A WBGT correction of 6-9 °C is necessary for individuals wearing SBA in the heat.

**Key Words:** thermoregulation, law enforcement, microclimate, WBGT, vest
DEDICATION

This dissertation is dedicated to everyone who helped me and guided me through the trials and tribulations of creating this manuscript. In particular, my family and friends who stood by me throughout the time taken to make this a reality.
# LIST OF ABBREVIATIONS AND SYMBOLS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
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<td>cm</td>
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<td>temp</td>
<td>Temperature</td>
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<td>rH</td>
<td>Relative humidity</td>
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<td>WBGT</td>
<td>Wet bulb globe temperature</td>
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<td>$T_{wb}$</td>
<td>Wet bulb temperature</td>
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<td>$T_{db}$</td>
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<td>$L \cdot \text{min}^{-1}$</td>
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<td>Kcals $\cdot \text{hr}^{-1}$</td>
<td>Kilocalories per hour</td>
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<tr>
<td>SBA</td>
<td>Soft body armor</td>
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<tr>
<td>$T_{re}$</td>
<td>Rectal temperature</td>
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HR  Heart rate
RPE  Ratings of perceived exertion
PARQ  Physical activity readiness questionnaire
SPSS  Statistical Package for the Social Sciences
TCS  Thermal comfort scale
=  Equal to
<  Less than
>  Greater than
\%  Percent
VO_2  Volitional oxygen consumption (aerobic capacity)
CDC  Centers for Disease Control and Prevention
NIOSH  National Institute of Occupational Safety & Health
ACGIH  American Conference of Governmental Industrial Hygienists
TLV  Threshold limit values
ACKNOWLEDGMENTS

First and foremost, thank you to my parents, without whom none of this would have been possible. They have always been there convincing me to do more than just ‘get by’. Thank you to my brothers who have helped me in more ways than I am sure they understand.

I owe most of who I have become as a professional to Dr. Andrew Bosak. He was always there to provide guidance or simply an avenue for me to vent through the dissertation process. I would not be as successful as I have become without his guidance and tutelage. Thank you to Stacy, Robert, and Charlie with whom I spent countless hours discussing and commiserating on the dissertation process. Thank you to my lab “minion” Bre, who was always there to collect data whenever I called on her. I want to especially thank the love of my life, Cassandra, who singlehandedly kept me sane throughout this process with her love and support.

I am indebted to my co-chairs Dr. Phillip Bishop and Dr. Gary Hodges. I cannot thank them enough for the guidance they provided. I also thank all of my committee members: Dr. John Higginbotham, who provided me with amazing guidance and reminding me “there are no good writers, just good re-writers”; Dr. Jonathan Wingo, who put up with my constant questions because he was there and his door was open; and Dr. Mark Richardson, who helped mold my dissertation into what it has become.

Thank you as well to the number of friends and family who have had an influence on my life. I thank the participants who volunteered their time and effort. This would never have been possible without their dedication.
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AUTHOR’S NOTE

All studies are written in journal format for the *Journal of Occupational and Environmental Hygiene*.

For the body of the dissertation, the following key will be used in reference to my own research.

It is my plan to publish all currently unpublished works in the following order:

**Study 1:** *Ambient Air Cooling for Concealed Soft Body Armor in a Hot Environment* – (Ryan et al, 20xxb)

**Study 2:** *Ambient Air Cooling for External Soft Body Armor in a Hot Environment* – (Ryan et al, 20xxc)

**Study 3:** *Effects of Macro Environments on Microclimate Under Soft Body Armor During Moderate Physical Exertion* – (Ryan et al, 20xxd)
CHAPTER I
INTRODUCTION

Large numbers of law enforcement and military personnel wearing soft body armor (SBA) are exposed to moderate-to-high ambient heat and humidity with low-to-moderate metabolic heat production for several hours creating high heat stress (Carter et al., 2005). For example, under certain conditions, when impermeable SBA must be worn to protect officers from hazards, the SBA may increase the microclimate under the SBA compared to the ambient wet bulb globe temperature (WBGT), which is a computed index of the environment that includes the potential for sweat evaporation as well as heat gain and loss from convection and radiation (estimated from Kenney, 1987; Reneau and Bishop, 1996). However, it should be noted that this heat gain is dependent upon macro-environment, work rate, and the SBA and clothing characteristics.

The increase in ambient WBGT is due to the weight of the SBA (~ 5 kg, depending on the level of SBA) and the lack of ventilation between the SBA and skin. The SBA impedes evaporative and convective cooling because it reduces sweat evaporation and air flow over a substantial portion of the body surface. These factors, coupled with the exposure to a warm environment and a moderate or higher work rate, greatly increases the likelihood of heat injury, dehydration, and impaired mental function. The increased risk of heat injury requires that accurate predictions of heat stress be available for officer safety and for work planning.

Federal guidelines (National Institutes for Occupations Hygiene [NIOSH]), and the threshold limit values (TLVs) set by The American Conference of Governmental Industrial
Hygienists (ACGIH) for work in the heat are based on WBGT. Environmental thresholds expressed as WBGT have been established for different metabolic rates (work demands) for cotton clothing. These thresholds indicate a 75/25% work/rest regimen for heat acclimatized, hydrated, fully clothed workers doing light manual labor in a WBGT of 30 °C, and a 25/75% regimen for heavy manual labor (ACGIH, 2006, 2008).

The equivalent knowledge of WBGT limits for law enforcement personnel safety wearing SBA is very limited. Although both NIOSH and ACGIH have an obligation to protect officers exposed to hot environments, current guidelines are based upon macro-environmental WBGT, with limited guidance for the additional heat stress from the SBA. Currently, there are no directly applicable standards for the SBA, which can cover more than 50% of the body surface area. Furthermore, there is limited research comparing the macro-environmental temperature to the micro-environment experienced while wearing SBA.

There has been previous research that examined various methods of cooling personnel wearing SBA. Studies have looked at: the addition of spacers to aid in passive cooling (Cheuvront et al., 2008; Ryan et al., 2012); air and liquid circulation devices (McLellan et al., 1999); and novel personal cooling devices (Barwood et al., 2009). Most of the studies that focused on passive cooling techniques reported either modest or no improvement in slowing the increase in core body temperature. While liquid circulation devices have been successful in reducing the rate of heat storage, these devices are limited in practicality, due to the additional weight and difficulty in supplying cooling.

Hadid et al. (2008) tested a commercially-available air cooling system (BREEZE, Rabintex, Israel) that blew ambient air across the torso (180 L · min⁻¹). This device was effective in reducing core body temperature (0.3 ± 0.2 °C), but the researchers noted modifications
including increasing air flow and increasing the size of the gap between the body and the SBA could result in greater cooling ability. Previous research in our lab (Ryan et al., 2012) has evaluated the use of standoffs in SBA to promote passive cooling and concluded that ventilation alone was unsuccessful in decreasing physiological strain. Currently, no study exists combining an air flow system with standoffs to promote cooling under a Level II SBA.

Most of the current literature deals with Level III or IV ballistic armor, which is commonplace among military personnel, but very little research exists on Level II SBA, which is standard issue SBA among law enforcement and safety personnel. In addition, the dual nature of Level II SBA to be worn either concealed or external to the shirt warrants research to determine the effect of heat on core body temperature while wearing a Level II SBA in both the concealed and external conditions.

Therefore, the purpose of this proposal is twofold: to evaluate the effect of ambient air cooling while wearing Level II SBA, in both the concealed and external state, in an environment that represents a typical summer day in the Southeastern United States in July (WBGT = 30 °C; dry bulb temperature [T_{db}] = 35 °C; wet bulb temperature [T_{wb}] = 27.6 °C; Relative Humidity [rH] = 57%) (ETB, 2011) and; to determine and attempt to establish WBGT adjustments for concealed Level II SBA at two macro- WBGTs (26 °C and 30 °C) during moderate intensity work.
CHAPTER II

AMBIENT AIR COOLING FOR CONCEALED SOFT BODY ARMOR IN A HOT ENVIRONMENT

ABSTRACT

Law enforcement and military personnel rely on soft body armor (SBA) for safety and protection. However, in hot environments the SBA inhibits convective and evaporative heat loss and increases heat storage, raising core body temperature. One way possibly to mitigate this excess heat storage is to promote air flow under the SBA. The purpose of this study was to evaluate the effect of ambient air induction on heat strain for participants wearing concealed SBA in a hot environment (WBGT = 30 °C). A counterbalanced, repeated measures protocol was performed with 9 volunteers (27 ± 4 yrs). Participants were fitted with either a traditional or modified Level II concealed SBA. The SBA was modified with 1.27 cm rubber standoffs and an ambient air induction system (~100 L · min⁻¹). Participants performed cycles of 12-min of walking (1.25 L · min⁻¹) and 3-min of arm curls (0.6 L · min⁻¹) with a 5-min rest after 30-min for a total of 60-min. The modified SBA led to an improvement in RPE after 30-min (p ≤ 0.05) and a reduction in microclimate compared to the control trial. However, the air induction system did not attenuate the rise in rectal temperature (p = 0.182) or heart rate (p = 0.306). These data suggest that the air induction system may provide small benefits while wearing a concealed Level II SBA in the heat, though improvements are needed to lessen physiological strain.

Key words: thermoregulation, law enforcement, microclimate, WBGT, vest
INTRODUCTION

Maintaining a stable core temperature during work in the heat is dependent on sufficient evaporation and convection. Convective heat loss is dependent on both a temperature gradient between the skin and the environment and the volume of air movement over the skin. If either these factors is impaired, less heat is dissipated, and, consequently, excess heat may be stored raising core body temperature.\(^{(1)}\)

Evaporation, through sweating, plays a critical role in maintaining normal body temperature during physical activity; however, sweating is most effective if humidity is low and air movement over the skin is high. If one or both of these factors is compromised, sweating becomes less effective, and the body may begin to store excess heat and this can impair physical and cognitive function.\(^{(1)}\)

Wearing soft body armor (SBA) when performing physical activity reduces convective and evaporative heat loss; consequently increased heat storage is more likely in this scenario. One way to possibly mitigate this heat storage while wearing SBA is to promote a “chimney effect”,\(^{(2)}\) which allows for heat to escape by increasing airflow between the skin and clothing through bodily movement or by creating venting. This process may be beneficial in reducing heat storage. Effective control of heat strain for individuals wearing SBA is a critical component for improving safety, comfort, and performance.\(^{(3)}\)

In the case of law enforcement and military personnel, where SBA use is required for long periods of time, often in conditions of elevated high heat and humidity. This results in an
increased risk of heat-related ailments such as dehydration, heat stress, heat stroke, and death.

Improvements in SBA cooling may be able to greatly reduce mortality and morbidity from vest noncompliance and from heat injury. The increase in risk of heat-related ailments is partly due to the weight of the SBA (~3 kg) and the lack of ventilation between the vest and skin. The SBA impedes evaporative and convective cooling because it reduces sweat evaporation and air flow on a substantial portion (>50%) of the upper-body surface.

One potential mechanism for promoting cooling and improving ventilation that our lab has tested previously is the implementation of 1.27 cm rubber standoffs applied directly to the SBA. The standoffs were designed to help improve ventilation and to allow excess heat, trapped under the SBA, to rise up and out of the uniform (“chimney effect”). However, this modification did not reduce heat storage, and it was concluded that additional intervention would be required.

Therefore, the purpose of this study was to evaluate the effect of ambient air induction on heat strain for participants wearing concealed SBA in a hot environment (wet bulb globe temperature [WBGT] = 30 °C). We hypothesized that the addition of ambient air flow under the SBA would provide effective cooling, resulting in lower rectal temperature during work, compared to a traditional SBA in a hot environment.

**METHODS**

**Research Design**

Participants performed two work trials in a hot environment in a counter-balanced, repeated measures design. One trial was with a non-modified, police standard issue SBA (Model 20, Level II, Point Blank Body Armor, Pompano Beach, FL) and one trial was with the modified
SBA with 1.27 cm standoffs described previously\(^4\) and a custom built ambient air induction system.

The air induction system was made from 1.27 cm flexible rubber tubing, perforated with 0.6 cm holes every 2.54 cm, attached to a 2000 W non-heated hair dryer (Black Bird, Conair, East Windsor, NJ). The system provided approximately 100 L · min\(^{-1}\) of ambient air flow. Trials with and without ambient air flow were conducted with the SBA concealed underneath a lightweight 65/35% cotton/polyester buttoned shirt, consistent with a ‘Class B’ Officer’s uniform. In each trial, participants worked until they reached the established termination limits of: work completion; rectal temperature (T\(_{rc}\)) exceeded 39 °C; heart rate exceeded 95% of maximum; any evidence of heat stress, such as chills, nausea, confusion, etc.; or volitional exhaustion.

Participants completed three laboratory sessions. The first visit was a briefing and introduction to the equipment and procedures. During this visit, each participant was fitted with the SBA to ensure proper standoff and air induction tubing placement; standoffs were placed to promote maximal lift. The second and third visits were for experimental trials under either air induction or non-modified conditions in counterbalanced order. Participant blinding was not practical for this study.

Participants completed a work paradigm that has been used in our laboratory\(^4-8\) consisting of treadmill walking and arm curls for a total of 60-min. Figure 1 illustrates the work protocol for the 60-min trials. The total work rate for the study trial was set at 300 Kcals · hr\(^{-1}\) (1.05 L · min\(^{-1}\) oxygen uptake [\(\text{VO}_2\)]). The walking component consisted of 12 min (80% of total work cycle time) of walking at 1.1 m · sec\(^{-1}\) and at a grade to elicit a metabolic rate of 350 Kcals · hr\(^{-1}\) (\(\text{VO}_2\) of 1.25 L · min\(^{-1}\)). The arm curls component consisted of 3-min (20%) of work
at a curl rate that elicited a metabolic rate of 180 Kcals \cdot hr^{-1} (0.6 L \cdot min^{-1}). Arm curls were done with a bar weighing 14.3 kg. Following the completion of every other work cycle (30-min of total work), the participant was allowed to sit and rest in the hot environment for 5-min before the start of the next work cycle.

Metabolic rate was measured by collecting and analyzing ventilatory expirations to determine oxygen utilization through indirect spirometry (trueONE, Parvo Medics, Sandy, UT). Work-rates were established during the initial 15 min of the first trial, and that work rate was fixed for all successive trials as in previous studies in our laboratory.\(^4\text{--}^8\) This work rate is classified as moderate work rate by the American Conference of Governmental Industrial Hygienists.\(^9\)

All trials were conducted in a heated chamber (WBGT = 30 °C; Dry Bulb Temperature \([T_{db}] = 35 \, ^\circ C\); Wet Bulb Temperature \([T_{wb}] = 27.6 \, ^\circ C\); relative humidity \([rH] = 57\%\)), until the termination criterion were met. This environment was chosen after averaging the temperature (34.7 °C), rH (57.6%), and WBGT (30 °C) during the afternoon in the month of July in 21 Southeastern cities in the United States.\(^10\) This environment was representative of a typical summer day in the Southeastern United States.

**Participants**

Following approval by the University Institutional Review Board, 9 healthy, male individuals (age 27 ± 4 yrs; ht 180.0 ± 6.8 cm; wt 79.8 ± 12.1 kg; BF% 14.9 ± 6.2%) were recruited for the study. Individuals who were interested in the study completed a PARQ and a Health History Questionnaire to determine their physical readiness before participating in the
study. Additionally, participants provided written informed consent prior to participation, and were re-consented prior to each trial.

**Familiarization Trial**

All willing and qualified participants reported to the laboratory to be introduced to the equipment used for the trials. Following completion of the informed consent and health history forms, participants had anthropometric measurements recorded (height, weight measured, and body fat percentage estimated from the sum of 3 skinfolds), then participants were fitted to the SBA and standoffs to ensure maximum lift and ventilation. The air induction system was fitted to the participant at this time, to allow the participant to feel comfortable with the system. During the familiarization trial, each participant was introduced to the flexible rectal thermocouple (model RET-1, Physitemp, Clifton, NJ) that was used to measure $T_{re}$. At the end of the familiarization visit, interested participants were instructed to refrain from heavy exercise, avoid alcohol, drink extra fluids (water), and to get plenty of sleep (at least 8 hr) the night before the experimental trials.

**Experimental Trials**

Participants underwent two work trials in a hot environment in a counter-balanced, repeated measures design. One trial was with a non-modified, police standard issue SBA and one trial was with the modified SBA with 1.27 cm standoffs and a portable air induction system. Upon arrival to the lab, urine specific gravity (USG) was measured using a handheld refractometer (SUR-Ne 2734, ATAGO, Tokyo, Japan) to ensure adequate hydration (USG $\leq 1.020$).
Participants were tested in attire equivalent to a law enforcement officer’s “Class B” uniform. This consisted of: 1) a cotton undershirt; 2) a lightweight (~170 g) 65/35% cotton/polyester buttoned shirt; and 3) a cotton/polyester blend trousers (~210 g). For safety and comfort, participants were required to wear their own sport shoes for the test. In addition to this attire, all participants wore a police standard issue concealed Level II SBA (Model 20, Level II, Point Blank Body Armor, Pompano Beach, FL) (~3 kg) during the two study trials.

Participants self-inserted a rectal thermocouple approximately 8 cm, indicated by a line on the thermocouple, past the anal sphincter.\(^{(12)}\) Participants also wore a heart rate monitor (Polar, New York, NY) to constantly measure heart rate during the trials.

In addition, prior to putting on the SBA on, iButtons (DS1923- Hygrochron, Embedded Data Systems, Lawrenceburg, KY) were placed on the center on the inside of the front and back of the SBA carrier to measure micro-environmental temperature and RH under the SBA during the trials at a rate of one sample every 60 seconds. After the iButtons were placed, the SBA was placed on the participant and the cotton polyester blend button down shirt was worn over the SBA and the participant entered the heated environmental chamber (WBGT = 30 °C).

As previously described, the work rate for every trial was set at 300 Kcals · hr\(^{-1}\) (1.05 L · min\(^{-1}\) VO\(_2\)), and consisted of a walking and arm curls component. During the experimental trials, measurements were recorded in the last 30 seconds of every 5-min interval.

All participants were asked to rate their thermal comfort on a scale (TCS) and perceived exertion (RPE) every 5 min and at the conclusion of each work bout. The thermal sensation scale was a 0.0 to 8.0 scale, in increments of 0.5 units, modified from Vokac, Kopke, and Keul.\(^{(13)}\) This scale used 4.0 as comfortable, 0.0 as unbearably cold, and 8.0 as unbearably hot. The RPE scale used was the Borg 6 to 20 scale with increments of 1.0.\(^{(14)}\) Micro-environmental
measurements were recorded every minute on the iButtons and were downloaded for analysis following completion of the trial. The time points 0, 15, 30, 45, and 60 min were chosen for analysis. After the 60 min trial, participants were removed from the chamber, asked to change out of their clothing and weighed again to estimate sweat loss.

**Statistical Analysis**

A power analysis was performed and revealed a sample size of \( n = 9 \) delivered sufficient power (power = 0.80) to detect a mean difference of 0.19 °C in rectal temperature in a one-tailed test, using the standard deviation of ± 0.21 °C, established from a previous study.\(^{(15)}\)

Data are presented as means ± SD. A two-way repeated measures ANOVA was used to assess the mean differences for physiological measures (\( T_{re} \), HR, Microclimate [Temp and rH], and sweat loss). Due to the small sample sizes and the violation of assumption of sphericity, within-subject effects were analyzed using the Greenhouse-Geisser correction. Post hoc Bonferroni analysis and paired samples t-tests (experiment-wise alpha set at 0.01) were conducted on all omnibus significant findings. Subjective measures (RPE and TCS) were analyzed using Wilcoxon Signed Ranks Tests. Data were analyzed using SPSS v. 19.0 (SPSS, Inc., Chicago, IL), and family-wise alpha was set at 0.05.

**RESULTS**

All nine participants successfully completed the 60-min work bout under both the control (CON) and modified (MOD) conditions. The macro-environment was maintained at a WBGT of 30.0 ± 0.2°C and a rH at 57 ± 3.2% for the duration of the 60-min work bouts.
Core Body Temperature

The change in $T_{re}$ was analyzed as $\Delta T_{re}$ from the variable “time” at baseline (0 min) to each time point analyzed (15, 30, 45, 60 min) between the two “conditions” CON and MOD. The $\Delta T_{re}$ results are displayed in Figure 2. A significant main effect of time was observed, $F(1.18, 9.45) = 45.31, p < 0.001$, for both the CON and MOD trials. As to be expected, $T_{re}$ rose significantly from baseline to the end of the 60-min work bout during both the CON and MOD trials. The air induction system did not differently affect $\Delta T_{re}$ as evidenced by a lack of a significant main effect of condition (CON, MOD) $F(1,8) = 21.02, p = 0.189$. End time $\Delta T_{re}$ was $0.4 \pm 0.2 \, ^{\circ}C$ under the MOD condition compared to $0.7 \pm 0.3 \, ^{\circ}C$ in the CON trial from the beginning to end of the work bout. The differences at 60-min approached statistical significance ($p = 0.048$) between the two trials.

Heart Rate

The change in HR was analyzed as $\Delta HR$ from the variable “time” at baseline (0 min) to each time point analyzed (15, 30, 45, 60 min) between the two “conditions” CON and MOD. The $\Delta HR$ results are displayed in Figure 3. A significant main effect of time was observed, $F(1.94, 15.55) = 36.95, p < 0.001$, for both the CON and MOD trials. As to be expected, HR rose significantly from baseline to the end of the 60-min work bout during both the CON and MOD trials. The air induction system did not differently affect $\Delta HR$ as evidenced by a lack of a significant main effect of condition (CON, MOD) $F(1,8) = 1.19, p = 0.371$. 
Ratings of Perceived Exertion (RPE)

A Wilcoxon Signed Ranks Test was conducted to compare participants’ RPE at 0, 15, 30, 45, and 60 min between the CON and MOD conditions. The results of the Wilcoxon Signed Ranks Test analysis are displayed in Figure 4. There was no difference in RPE at any time point during the first 30-min of the work bout. Significantly lower self-reported RPE were noted at the 45 min (p = 0.02) and 60 min (p = 0.03) time points under the MOD condition.

Thermal Comfort Scale (TCS)

A Wilcoxon Signed Ranks Test was conducted to compare participants’ TCS at 0, 15, 30, 45, and 60 min between the CON and MOD conditions. The results of the Wilcoxon Signed Ranks Test analysis are displayed in Figure 5. There was no difference in TCS at any time point during the 60-min of the work bout. TCS scores approached significance at the 45-min (p = 0.052) and 60-min (p = 0.058) marks.

Sweat Loss

Sweat loss was estimated as the difference in participant seminude (boxers only) body weight prior to and immediately following the 60-min work bout. No significant differences were noted between the two conditions (p = 0.40). Participants lost an average of 0.57 ± 0.23 kg under the CON condition and 0.59 ± 0.21 kg under the MOD condition.

Microclimate

Figure 6 represents the average microclimate (temperature and relative humidity) for the variables: a) Front Temp; b) Back Temp; c) Front rH; and d) Back rH over the 60-min work
bouts. Significant main effects for the variable “time” were observed for all microclimate
variables (p ≤ 0.001).

A significant interaction for the variables “condition x time” was observed for Front
Temp, F(2.402,19.215) = 3.695, p = 0.037. Paired samples t-tests were conducted and noted that
the MOD condition maintained lower front temperatures at the 15-min (p = 0.004), 30-min (p =
0.001), 45-min (p = 0.002), and 60-min (p = 0.002) time points. The MOD temperatures were on
average 1.0 ± 0.2 °C lower than CON during the 60-min work bout.

A significant main effect for the variable “condition” was observed for Front rH, F(1,8) =
19.232, p = 0.002. Paired samples t-tests were conducted and noted that the front rH under the
MOD condition was lower at the 15-min (p = 0.005) time point compared to CON. Significance
was approached at all other time points analyzed: 30-min (p = 0.023); 45-min (p = 0.091); and
60-min (p = 0.023). The MOD rH were on average 4.1 ± 1.0 %rH lower than CON during the
60-min work bout. The interaction between “condition x time” approached significance for the
front rH variable (p = 0.079).

A significant interaction for the variables “condition x time” was observed for Back
Temp, F(2.066,16.527) = 4.766, p = 0.02. Paired samples t-tests were conducted and noted that
the MOD condition maintained lower back temperatures at the 15-min (p = 0.002), 30-min (p =
0.001), 45-min (p = 0.003), and 60-min (p = 0.002) time points. The MOD temperatures were on
average 1.1 ± 0.3 °C lower than CON during the 60-min work bout.

A significant main effect for the variable “condition” was observed for Back rH, F(1,8) =
11.697, p = 0.009. Paired samples t-tests were conducted but failed to note the time points where
significance existed, suggesting the post hoc analysis was not sensitive enough to detect where
the difference occurred. Significance was approached at all time points analyzed: 15-min
The MOD rH were on average 2.8 ± 0.8 \%rH lower than CON during the 60-min work bout. The interaction between “condition x time” was not significant (p = 0.121).

Compared to macroclimate (35 °C, 57\% rH), microclimate (temperature and relative humidity) for both conditions were significantly higher at the end of the 60-min work bout (p ≤ 0.01 for both variables).

DISCUSSION

The purpose of this study was to evaluate the effect of modifying a Level II SBA with spacing and ambient air induction on heat strain and subjective measurements for participants performing moderate intensity work in a hot environment (WBGT = 30 °C) while wearing a concealed Level II SBA. This study demonstrated that spacing the SBA off the body and introducing ambient airflow led to lowered perceived exertion levels, and slightly lower microclimate temperature and humidity. Though none of these changes were large, all of these factors play a role in lessening the risk of heat illness and perception of effort when performing work in a hot and humid environment.

Previous attempts to provide passive cooling by standing SBA off the body had proven unsuccessful in attenuating increases in core body temperature.\(^4,16\) Ambient air systems have been tested on higher levels of SBA (e.g. military, Special Weapons and Tactics [S.W.A.T.] Team) and increased the time to exhaustion\(^{17,18}\) and decreased physiological strain (\(T_{re}, T_{sk}, HR\)).\(^{15,18,19}\) Our laboratory, previously noted a difference between the macroclimate (32 °C; 60 \%rH) and the microclimate under the SBA (36.8 °C; 97.4 \%rH).\(^4\) A similar difference between the macro- (35 °C; 57 \%rH) and micro- environments (front: 36.8 °C; 95.0 \%rH; back:
37.5 °C; 98.1 %rH) was seen in the present study. This difference between macro- and micro-environments quantifies the degree to which wearing a SBA increases the thermal strain of the individual, and can be potentially hazardous in a hot environment. Our data indicate that in just 60-min of moderate intensity work, an individual wearing a concealed Level II SBA lost about 0.5 kg in sweat. Extrapolated over a typical eight-hour shift, an individual could lose almost 4 L in sweat under these conditions.

The air induction system built for this study failed to significantly reduce thermal strain (decreased Δ T_{re}) but supplied only about 55% (~ 100 L · min⁻¹) of that reported for a commercially available ambient air system (e.g. 180 L · min⁻¹, BREEZE Vest, Rabintex, Israel). Hadid, Yanovich, Erlich, Khomenok, and Moran⁵ conductor a study with the BREEZE Vest at two climates (40 °C, 40%rH; 35 °C, 60%rH) and noted a reduction in T_{re} increase of 0.26 ± 0.20 °C and 0.34 ± 0.21 °C, respectively. It is possible that the custom built air induction system tested in this study did not provide enough airflow to attenuate a rise in T_{re}.

The reduction in T_{re} from MOD to CON was not statistically significant at any time point during the course of the 60-min work bout. Rises in T_{re} were very similar during the first 30-min of each work bout. After 30-min, it appeared that changes in T_{re} were beginning to become less pronounced in the MOD condition compared to the CON condition. While not significant at the end of the 60-min work bout (p = 0.048), longer duration testing should be conducted to see if a significant difference in the T_{re} increase exists as work continues.

While a significant decrease in microclimates was noted under the MOD condition, it should be noted that the difference in temperature (Front: 1.0 ± 0.2 °C; Back: 1.1 ± 0.3 °C) and relative humidity (Front: 4.1 ± 1.0 %rH; Back: 2.8 ± 0.8 %rH) between the two conditions was small. As the work bout approached 60-min, both CON and MOD had higher microclimate
temperatures than at baseline and a microclimate rH of nearly 100% on the back. This could be due to the limited ventilation of the 65/35% cotton/polyester uniform shirt, especially in the back with no buttons or collar opening. This modest decrease in microclimate may not be practically important, though the decrease also was associated with lower reported RPE after 45-min.

Increases in the rate of air flow in the air induction system could improve the reductions in microclimate and thermal strain. Improvements to the uniform shirt may also improve the air induction system effectiveness and provide reductions in thermal strain. For example, employing a more breathable or mesh fabric may allow for more heat to escape a ventilated SBA.

While a significant reduction was noted for RPE, subjective improvements in perception of effort (RPE) and comfort (TCS) were less pronounced than expected. It should be noted that participant-reported thermal comfort approached significance at both the 45-min (p = 0.052) and 60-min (p = 0.058) time points. It has been speculated that the peripheral thermoreceptors may adapt to the continuous air blowing. This adaptation may result in participants not perceiving a cooling effect, even though a physiological improvement has occurred. Studies that have focused on intermittent cooling techniques have noted pronounced subjective comfort results compared to the current study that used continuous 35 °C air flow. It is possible that providing an intermittent stimulus to the peripheral thermoreceptors may result in more subjective comfort.

This study was limited by a number of factors. While the custom air induction system was modestly effective in decreasing thermal stress, increasing airflow could further increase both physiological and psychological benefits. Additionally, due to the design of the vest and fluctuations in body temperature due to menstruation, female participants were not included in
this study, though they make up over 15% of federal law enforcement officers. Future research should look to see how female participants react to air induction.

CONCLUSIONS

In conclusion, the evaluation of the air induction system used in this study suggests that a combination of ventilation (via standoffs) and air induction slightly blunted physiological stress (change in microclimate) and improved subjective comfort for individuals performing moderate physical activity while wearing concealed Level II SBA in a simulated environment typical of an average summer day in the Southeastern United States. However, the modified vest did not attenuate the rise in $T_{re}$ during the 60-min bout under these conditions. Further testing with intermittent or higher flow rates or longer duration testing is needed.
REFERENCES


9 2008 TLVs and BEIs - Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists (ACGIH).


FIGURE 1. Work paradigm for the 60-min work trials in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD).

<table>
<thead>
<tr>
<th>Work Paradigm 300 Kcals · hr⁻¹ (1.05 L · min⁻¹ VO₂)</th>
<th>Work Paradigm 300 Kcals · hr⁻¹ (1.05 L · min⁻¹ VO₂)</th>
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<th>Work Paradigm 300 Kcals · hr⁻¹ (1.05 L · min⁻¹ VO₂)</th>
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<tbody>
<tr>
<td>Part. Prep ~10min</td>
<td>Break 5min</td>
<td>Break 5min</td>
<td>End Prep 5min</td>
</tr>
<tr>
<td>~15min</td>
<td>15min</td>
<td>15min</td>
<td>5min</td>
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<tr>
<td>USG, Weight, T&lt;sub&gt;re&lt;/sub&gt;, Dress, SBA</td>
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<tr>
<td>1 Cycle of: Walking: 12 min (2.5mph) 350 Kcals · hr⁻¹ (VO₂:1.25 L · min⁻¹) Arm curls: 3 min (14.3kg) 180 Kcals · hr⁻¹ (0.6 L · min⁻¹)</td>
<td>1 Cycle of: Walking: 12 min (2.5mph) 350 Kcals · hr⁻¹ (VO₂:1.25 L · min⁻¹) Arm curls: 3 min (14.3kg) 180 Kcals · hr⁻¹ (0.6 L · min⁻¹)</td>
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<td>1 Cycle of: Walking: 10 min (2.5mph) 350 Kcals · hr⁻¹ (VO₂ of 1.25 L · min⁻¹)</td>
</tr>
</tbody>
</table>

T<sub>re</sub>, HR, RPE, TCS, macroclimate assessed every 5 min
FIGURE 2. Mean rectal temperature change [$\Delta T_{re}$ ($T_{60} - T_0$)] of 9 participants during 60-min work trials (cycles of 12 min walking and 3 min arm curls, with 5 min break after 30-min) in a 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. There was no significant difference between treatments.
FIGURE 3. Mean HR change [Δ HR (HR_{60} – HR_{0})] of 9 participants during 60-min work trials (cycles of 12 min walking and 3 min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. No significant difference was noted between the two conditions.
FIGURE 4. Ratings of perceived exertion values of 9 participants during 60-min work trial (cycles of 12 min walking and 3 min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. * Denotes significance at p ≤ 0.05.
FIGURE 5. Thermal comfort scale values of 9 participants during 60-min work trial (cycles of 12 min walking and 3 min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. No significant difference existed between the two conditions.
FIGURE 6. Mean microclimate (temperature [°C]; relative humidity [%RH]) data of 9 participants during 60-min work trial (cycles of 12 min walking and 3 min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). * Denotes significant difference between treatments at $p \leq 0.01$. Dotted line at 35 °C and 57%RH represents macroclimate during work bout. Data are presented as means ± SD.
CHAPTER III

AMBIENT AIR COOLING FOR EXTERNAL SOFT BODY ARMOR IN A HOT ENVIRONMENT

ABSTRACT

Previously we have studied the impact of an ambient air induction system on heat storage in concealed soft body armor (SBA) in a hot environment (wet bulb globe temperature [WBGT] = 30 °C) over 60 min of exercise. The Level II SBA is also regularly worn in a non-concealed manner outside the shirt. The purpose of this study was to investigate the effects of adding an ambient air system with 1.27 centimeter standoffs to a Level II SBA, worn externally, on heat strain and perceived comfort compared to an unmodified SBA worn externally. Nine participants (27 ± 4 years) completed two 60-min work bouts (cycles of 12-min walking, 3-min arm curls) in a counter-balanced manner with control and modified external SBAs. No significant differences in rectal temperature, heart rate, ratings of perceived exertion, or thermal comfort were detected between the SBA trial and the SBA modified with the ambient air system. The microclimate under the modified SBA was significantly lower for front (0.4 ± 0.1 °C) (p = 0.027) and back temperature (1.2 ± 0.2 °C) (p = 0.001) and back relative humidity (4.7 ± 1.2 %rH) (p = 0.004) following the 60-min work bout. This small change in microclimate was not associated with reduced physiological (change in rectal temperature, or heart rate) or psychological (ratings of perceived exertion, or thermal comfort) strain in individuals wearing a modified non-concealed Level II SBA in a hot environment. Further improvements to the
ambient air system (increased airflow, change in shirt fabric) are needed to achieve reductions in physiological and psychological strain.

**Key words:** thermoregulation, law enforcement, microclimate, WBGT, vest
INTRODUCTION

Heat stress can threaten the life, health, and performance of law enforcement and military personnel. Soft body armor (SBA) is an impermeable, moderately heavy (~3-9 kg, depending on model) material, that covers about of 50% of the upper-body surface area, and has been shown to increase heat stress and core body temperature, which can lead to dehydration, heat illness, and death.\(^{(1-4)}\) Wearing SBA has also been shown to hinder physical performance associated with military and law enforcement duties and increases in subjective feelings of effort.\(^{(5)}\)

Previously, we\(^{(1)}\) (Ryan et al, 20xxb) and others have evaluated strategies to mitigate the heat storage associated with SBA through passive\(^{(2)}\) and active\(^{(3, 6)}\) cooling techniques with varying degrees of success. In our previous study (Ryan et al, 20xxb), 1.27 cm standoffs and an air induction system were used to promote cooling under a Level II SBA worn concealed in a hot environment. That study noted an improvement in self-reported effort (RPE) after 45-min in the modified air induction (MOD) condition compared to the unmodified control (CON) condition. However, concealment of SBA represents only one condition in which SBA is worn by law enforcement and military personnel.

Level II SBA can be worn over, or external to the uniform shirt, which could increase ventilation because there is no outer layer of clothing to interfere with air flow under the SBA. However, the additional layer of clothing between the body and SBA absorbs sweat, and may contribute to a decrease in convective and evaporative skin cooling. Therefore, introducing constant ambient airflow under the SBA may increase convective and evaporative heat loss.
Air cooling has been tested on Level III and IV SBA and other hard armor that is used by military personnel. These studies have noted the introduction of both ambient\(^{(6)}\) and cool air\(^{(5)}\) reduced thermal strain in individuals working in the heat. No study exists testing the effect of ambient air induction on external Level II SBA, which is most commonly used by law enforcement personnel.

Therefore, the purpose of this study was to evaluate the effect of ambient air induction on heat strain for individuals wearing external, non-concealed Level II SBA in a hot environment (wet bulb globe temperature [WBGT] = 30 °C). We hypothesized that the addition of ambient air flow under the externally worn SBA would provide physiological (change in \(T_{re}\), HR, micro-WBGT) and psychological (RPE, TCS) benefits compared to a typical (unventilated) external SBA in a hot environment.

**METHODS**

**Research Design**

The research design for this study was similar to our previous study (Ryan et al., 20xxb). In short, participants underwent two work trials in a hot environment in a counter-balanced, repeated measures design. One trial was with a non-modified, police standard issue SBA and one trial was with the same modified Level II SBA with 1.27 cm standoffs and an air induction system used in the previous study (Ryan et al., 20xxb). Both trials were conducted with the SBA worn over (external) a lightweight 65% cotton/35% polyester buttoned shirt, consistent with a ‘Class B’ Officer’s uniform.

As with the Ryan et al. (20xxb) study, participants completed three sessions: 1) a briefing and introduction to the equipment and procedures; 2) work study trial #1 under one SBA
ventilation condition; 3) work study trial #2, counterbalanced under the alternate condition. As with the previous study, all trials were conducted in a heated chamber simulating a July afternoon in the Southeastern United States (WBGT = 30 °C) until any of the established termination limits of: work completion; T_e above 39 °C; heart rate (HR) above 95% of maximum; evidence of heat stress (chills, nausea, confusion, etc.); or volitional exhaustion was met. Participant blinding was not practical for this study.

The metabolic rate (1.05 L · min⁻¹ VO₂: 300 Kcals · hr⁻¹), for the trials were identical to Ryan et al. (20xxb). Refer to Ryan et al. (20xxb) for detailed description of work rate and paradigm. In brief, participants walked 12-min at a metabolic rate of 350 Kcals · hr⁻¹ (1.25 L · min⁻¹) and 3-min of arm curls at a metabolic rate of 180 Kcals · hr⁻¹ (0.6 L · min⁻¹), with a 5-min rest after 30-min of work for a total of 60 min. This work rate is classified as moderate work rate by the American Conference of Governmental Industrial Hygienists(7) and has been used by this laboratory in many previous studies,(1, 8-12) (Ryan et al, 20xxb)

**Participants**

There were 9 healthy male individuals (age 27 ± 4 yrs; ht 180.0 ± 6.8 cm; wt 79.8 ± 12.1 kg; body fat% 14.9 ± 6.2%). All participants were informed of the nature of the study, any and all health risks, and completed all pertinent health forms (Physical Activity Readiness Questionnaire, Health History Questionnaire). Participants also provided written informed consent prior to participation, and re-consent prior to each work trial. All procedures in this study were approved by the University Institutional Review Board prior to completion of any work by participants.
Familiarization Trial

All participants reported to the Human Performance Lab where all pertinent forms were completed, anthropometric measurements were taken, including body fat percentage, and the SBA standoffs, and air induction system were fitted. At the end of the familiarization visit, participants were instructed to refrain from heavy exercise, avoid alcohol, drink extra fluids (water), and get plenty of sleep (at least 8 hr) the night before the experimental trials.

Experimental Trials

The purpose of this study was to examine the effect of standoffs and an ambient air induction system on an external SBA worn in a hot environment. The methodology and procedures for the experimental trials for this study were identical to the experimental trials conducted by Ryan et al. (20xxb), except for SBA positioning. In brief, participants wore a “Class B” law enforcement uniform and police standard issue SBA (Model 20, Level II, Point Blank Body Armor, Pompano Beach, FL) and performed two, counter-balanced, repeated measures, bouts of 60 min of exercise in a hot environment consistent with a July summer in the Southeastern United States (WBGT = 30 °C). One trial was conducted with a non-modified external SBA, and the other trial used a modified SBA with an identical ambient air system used by Ryan et al. (20xxb).

The work rate for both trials was set at 300 Kcals · hr⁻¹ for the total of the 60-min trial. All test variables: T⊥; HR; ratings of perceived exertion (RPE); ratings of thermal comfort scale (TCS); and macro-WBGT (temperature and humidity) were measured in the last 30 s of every 5 min. Microclimate (temperature [°C]; relative humidity [% rH]) data were recorded every minute using iButtons (DS1923- Hygrochron, Embedded Data Systems, Lawrenceburg,
KY) placed on the front and back in the center of the SBA carrier outside the shirt for: a) Front Temp; b) Back Temp; c) Front rH; and d) Back rH during the 60-min work bouts. Following completion, participants were weighed to estimate sweat loss.

**Statistical Analysis**

An *a priori* power analysis revealed that a sample of 9 participants was sufficient to elicit an acceptable power to detect a mean difference of 0.19 °C in rectal temperature. Data are presented as means ± SD. Repeated measures two-way ANOVAs were used to assess the mean differences for physiological measures (\(T_{re}\), HR, Microclimate [Temp and rH], and sweat loss). Post hoc Bonferroni analysis and paired samples t-tests (experiment-wise alpha set at 0.01) were conducted for all significant findings. Psychological measures (RPE and TCS) were analyzed using Wilcoxon Signed Ranks Tests. Data were analyzed using SPSS v. 19.0 (SPSS, Inc., Chicago, IL), and family-wise alpha was set at 0.05.

**RESULTS**

All 9 participants successfully completed the 60-min work bouts under both conditions (CON and MOD) at a maintained WBGT of 30.0 ± 0.3°C (\(T_{db}\) = 35.0 ± 0.2°C; \(T_{wb}\) = 27.5 ± 0.4°C; rH = 57 ± 3%).

**Physiological Measures**

*Core Body Temperature*

The change in \(T_{re}\) was analyzed as \(\Delta T_{re}\) from the variable “time” at baseline (0 min) to each time point analyzed (15, 30, 45, 60 min) between the two “conditions” CON and MOD. The \(\Delta T_{re}\) results are displayed in Figure 1. \(T_{re}\) rose significantly \((F[1.618, 12.946] = 34.863, p < \)
0.001) from baseline (0 min) to the end of the 60-min work bout during both the CON and MOD trials. The air induction system did not differently affect Δ $T_{re}$ as evidenced by a lack of a significant main effect of condition (CON, MOD) $F(1,8) = 0.213, p = 0.657$. No significant interaction of condition x time was observed, $F(1.288, 10.308) = 0.173, p = 0.747$.

**Heart Rate**

The change in HR was analyzed as Δ HR from the variable “time” at baseline (0 min) to each time point analyzed (15, 30, 45, 60 min) between the two “conditions” CON and MOD. The Δ HR results are displayed in Figure 2. A significant main effect of time was observed, $F(2.277, 18.213) = 50.401, p < 0.001$. HR rose significantly from baseline to the end of the 60-min work bout during both the CON (31 ± 12 bpm) and MOD (27 ± 10 bpm) trials. There was no significant difference ($p = 0.554$) in Δ HR between CON and MOD at baseline (0 min). The air induction system did not differently affect Δ HR as evidenced by a lack of a significant main effect of condition (CON, MOD) $F(1,8) = 1.659, p = 0.234$.

**Sweat Loss**

Sweat loss was established as the difference in participant seminude (boxers only) body weight prior to and immediately following the 60-min work bout. There was no sweat loss difference detected ($p = 0.138$) between CON and MOD trials. Participants lost an average of 0.6 ± 0.1 kg and 0.5 ± 0.2 kg during the CON and MOD trials.
**Microclimate**

Figure 3 represents the average microclimate (temperature [°C] and relative humidity [%rH]) for the variables: a) Front Temp; b) Back Temp; c) Front rH; and d) Back rH over the 60-min work bouts. Significant main effects for the variable “time” were observed for all microclimate variables (p ≤ 0.001).

A significant main effect for the variable “condition” (CON, MOD) was observed for Front Temp, $F(1, 8) = 7.275, p = 0.027$. The MOD temperatures were on average 0.4 ± 0.1 °C lower than CON during the 60-min work bout. Paired samples t-tests were conducted but failed to note the time points where significance existed, suggesting the post hoc analysis was not sensitive enough to detect where the difference occurred. Significance was approached at the 15-min (p = 0.025) and 30-min (0.086) time points.

Relative humidity rose significantly (p ≤ 0.001) during the 60-min work trials under both CON (28.4 ± 5.0 %rH) and MOD (21.5 ± 12.7 %rH) conditions. No main effect for the variable “condition” was observed for Front rH, $F(1,8) = 4.315, p = 0.071$. Large SD (~12 %rH) existed under the MOD condition at all times points analyzed during the work bout.

A significant main effect for the variable “condition” was observed for Back Temp, $F(1, 8) = 26.684, p = 0.001$. Back temperatures were significantly lower compared to CON at the 30-min (p = 0.002), 45-min (p ≤ 0.001), and 60-min (p = 0.001) time points. The MOD temperatures were on average 1.2 ± 0.2 °C lower than CON during the 60-min work bout. The interaction between “condition x time” approached significance (p = 0.096).

A significant main effect for the variable “condition” was observed for Back rH, $F(1,8) = 15.309, p = 0.004$. Paired samples t-tests were conducted and noted that MOD back rH were significantly lower than CON at the 15-min (p = 0.005), 30-min (p = 0.009), and 45-min (p =
Significance was approached at the 60-min time point (p = 0.014). The MOD rH were on average $4.7 \pm 1.2\% rH$ lower than CON during the 60-min work bout. The interaction between “condition x time” was not significant (p = 0.118).

**Psychological Measures**

No significant difference in RPE (Figure 4) was detected at any time point during the 60-min of the work bout between the CON and MOD conditions (p > 0.05). RPE values were identical at the 15, 30, and 45 min time points. TCS scores (Figure 5) were not significantly different between the CON and MOD conditions at any of the time points. The air induction system did not improve self-reported subjective measures of effort or comfort during the 60-min work bout, under these conditions.

**DISCUSSION**

The purpose of this study was to evaluate the effect of an ambient air induction system on external Level II SBA in a hot environment. The results of this study suggest that the introduction of ambient air under the external SBA was not effective in decreasing rectal temperature, heart rate, or sweat loss, or improving subjective measures of effort and comfort. Therefore, the use of an ambient air induction system for externally worn SBA was ineffective under these conditions.

Several studies have tested the efficacy of ambient\(^{(3, 6, 17)}\) and cooled\(^{(19, 20)}\) air induction systems on different levels of SBA. These studies have shown that air induction is effective in: increasing time to exhaustion;\(^{(6, 17)}\) lessening physiological strain associated with wearing SBA in the heat;\(^{(3, 17, 18)}\) and lower participant reported levels of effort and comfort.\(^{(19, 20)}\)
Our laboratory (Ryan et al, 20xxb) previously looked at the efficacy of the same air blowing system used in this study on a Level II SBA worn concealed under a uniform shirt. In that study, we noted an improvement in self-reported effort (RPE) after 45-min in the MOD condition compared to CON. Additionally, the temperatures (Front: 1.0 ± 0.2 °C; Back: 1.1 ± 0.3 °C) and relative humidity (Front: 4.1 ± 1.0 %rH; Back: 2.8 ± 0.8 %rH) were significantly lower in the MOD condition compared to CON. Similar changes in temperature (Front: 0.4 ± 0.1 °C; Back: 1.2 ± 0.2 °C) and relative humidity (Front: 6.7 ± 3.2 %rH; Back: 4.7 ± 1.2 %rH) existed in the current study. It is important to note that the micro-environmental measures made in the current study were made outside the shirt rather than next to the skin. In our previous study on concealed SBA, the micro-WBGT was measured under the shirt, and the SBA. This difference should be considered in interpreting this study.

We found no differences between the CON and MOD conditions for any of the physiological measures ($T_{re}$, sweat loss, HR) tested. Differences in temperature were more noticeable on the back (CON 37.1 ± 0.2 °C; MOD 35.6 ± 0.9 °C) than the front (CON 36.5 ± 0.7 °C; MOD 36.3 ± 0.6 °C) of the body. The rHs were lower in the front of the body (CON 89.7 ± 5.3%; MOD 81.3 ± 12.7%) compared to the back of the body (CON 98.6 ± 0.7%; MOD 94.7 ± 4.2%). The large SDs of rH, particularly in the front in the MOD condition where SD at each time point analyzed other than 0 min, was over 10%, which may mask any benefits of the air induction system. Additional testing is needed to determine if this large rH variability is consistent for non-concealed SBA.

The reason why the air induction system tested in the current study did not result in a reduction in physiological strain, as previous studies have seen, is not clear. The volume of air produced with the air induction system in the current study was only about 55% of that reported
for commercially available systems (e.g. 180 L · min⁻¹, BREEZE Vest, Rabintex, Israel). Increasing airflow would potentially provide cooling under the vest, which could aid in lessening the physiological strain associated with wearing SBA in the heat. Additionally, the fabric of the uniform shirt may also limit the effectiveness of the air induction system. The 65/35% cotton-polyester shirt used in the current study may have limited the amount of air to penetrate the fabric, which could reduce the effectiveness of the system.

Additionally, no improvements in subjective measures of comfort (TCS) and effort (RPE) were noted among the participants. It is possible that due to the fabric of the uniform shirt, that too little air penetrated to the skin to aid in evaporative cooling. Anecdotally, a few participants stated they could not feel the flow of air through the shirt, though the system was functioning properly. The introduction of a breathable fabric uniform shirt may provide more avenues for heat to escape the torso, air to reach the skin, and promote more evaporation of sweat, which would help lessen the physiological strain and improve comfort.

It was thought that the induction of external air may provide cooling effects on externally worn SBA due to the increase in convective and evaporative cooling that the airflow would provide. The lack of difference in sweat loss (p = 0.14) between the CON (0.6 ± 0.1 kg) and the MOD (0.5 ± 0.2 kg) condition and lack of improved comfort (p = 0.16) and reduced effort (p = 0.74) at the end of the 60 min work bout, provides evidence that the air induction system was not effective when SBA is worn externally under these conditions. The lack of improvements could be due to the uniform shirt not allowing air to reach the skin to aid in evaporative cooling.

The current study focused only on male participants due to the design of the SBA available for study. Future studies should focus on SBA designed for female law enforcement
personnel, who make up about 15% of federal law enforcement officers\textsuperscript{(21)} to determine the effectiveness of air induction on female law enforcement personnel.

**CONCLUSIONS**

In conclusion, the air induction system used in the current study was not effective in decreasing physiological ($T_{re}$, HR, sweat loss) strain or improve psychological (TCS, RPE) measures of comfort and effort during the 60-min work bout. Further improvements to the air induction system to provide more airflow, or better distribution of air are needed to provide a cooling effect.
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7 2008 TLVs and BEIs - *Threshold limit values for chemical substances and physical agents and biological exposure indices*. Cincinnati, OH: American Conference of Governmental Industrial Hygienists (ACGIH).


FIGURE 1. Mean rectal temperature change [$\Delta T_{re} (T_{60} - T_0)$] of 9 participants during 60 min work trial (cycles of 12 min walking and 3 min arm curls, with 5 min break after 30 min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. No significant differences existed between the two conditions at any of the time points analyzed.
FIGURE 2. Mean HR change [Δ HR (HR₆₀ – HR₀)] of 9 participants during 60-min work trial (cycles of 12-min walking and 3-min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. No significant differences existed between the two conditions at any of the time points analyzed.
FIGURE 3. Mean microclimate (temperature [°C]; relative humidity [%RH]) data of 9 participants during 60-min work trial (cycles of 12-min walking and 3-min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. *Denotes significance at \( p \leq 0.01 \). Dotted line at 35 °C and 57%rH represents macroclimate during work bout.
FIGURE 4. Ratings of perceived exertion values of 9 participants during 60-min work trial (cycles of 12 min walking and 3 min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. No significant differences existed between the two conditions at any of the time points analyzed.
FIGURE 5. Thermal comfort scale values of 9 participants during 60-min work trial (cycles of 12 min walking and 3 min arm curls, with 5-min break after 30-min) in 30 °C WBGT environment wearing a non-modified Level II SBA (CON) or a SBA modified with an ambient air induction system (MOD). Data are presented as means ± SD. No significant differences existed between the two conditions at any of the time points analyzed.
CHAPTER IV
MICROCLIMATE UNDER SOFT BODY ARMOR DURING MODERATE PHYSICAL EXERTION

ABSTRACT

Previous research has studied the impact of Level II concealed soft body armor (SBA) on the attenuation of heat storage in a hot environment simulating a typical summer day in the Southeastern United States (WBGT = 30 °C) and noted a significant differences between macro- and micro-WBGT. The purpose of this study was to characterize the microclimate (micro-WBGT) under a concealed Level II SBA during 60-min of moderately intense work at two separate macro-WBGTs (26 °C and 30 °C), and to establish WBGT corrections to allow prediction of heat strain in an individual wearing a concealed Level II SBA. A single trial was performed with 9 volunteers (27 ± 4 yr) outfitted with a standard law enforcement uniform and a traditional concealed Level II SBA, in a moderately warm environment (WBGT = 26 °C). Each participant performed cycles of 12-min of walking (1.25 L · min⁻¹) and 3-min of arm curls (14.3 kg, 0.6 L · min⁻¹) with a 5-min rest after every other cycle, for a total of 60-min. This trial was compared to a previously completed 60-min work bout at 30 °C. A two-way repeated measures ANOVA with Post hoc Bonferroni and paired samples t-test analysis was conducted using the variables “temp” and “time”. The results indicate that a greater difference between macro-micro-WBGTs existed at 26 °C compared to the 30 °C macro-WBGT. Moderate work in Level II SBA requires a WBGT correction of 9.6 °C and 6.6 °C at macro-WBGTs of 26 °C and 30 °C,
respectively. A modified simple linear regression prediction model was established for mean Micro-WBGT for each macro-WBGTs after the plateau point at the 30-min mark. The derivation regressions at 26 °C ($R^2 = 0.99$), and 30 °C ($R^2 = 0.99$) indicate that micro-WBGT could be predicted for each 15-min time at both macro-WBGTs tested for individuals doing moderate intensity (300 Kcals · hr$^{-1}$) work wearing concealed Level II SBA.

**Key words:** thermoregulation, law enforcement, WBGT, vest
INTRODUCTION

The Centers for Disease Control and Prevention (CDC) estimate that nearly 700 individuals die annually from exposure to environmental heat.\(^{(1)}\) The main issue for work in moderate to hot environments is the increase in core body temperature as a result of excess stored heat, which can lead to dehydration, heat strain, and death.\(^{(2)}\) Law enforcement personnel are particularly vulnerable to heat illnesses due to long hours of patrol outside, regardless of hot temperatures, but also the addition of soft body armor (SBA), which can weigh 3-9 kg depending on the model worn; SBA greatly inhibits convective and evaporative sweat loss.

Better understanding of the heat stress that officers face can be used to help improve comfort and safety and benefit both the officer and the public. While some research exist examining the impact of body armor on heat stress, most published research has focused on Level III and higher body armor, which is more commonly worn by military personnel.\(^{(3,4)}\)

Current federal guidelines from the National Institutes for Occupations Hygiene,\(^{(5)}\) and the threshold limit values (TLVs) set and updated by The American Conference of Governmental Industrial Hygienists (ACGIH) for protective clothing are based on ambient wet bulb globe temperature (WBGT).\(^{(6)}\) Environmental thresholds expressed as WBGT have been established for different metabolic rates (work demands) for cotton clothing.

Clothing adjustment factors for TLVs exist for a variety of protective clothing, such as coveralls, and can add ~ 11 °C to the WBGT depending on the type and permeability of the clothing.\(^{(6,7)}\) These guidelines and thresholds are limited because these corrections are not
constant, and can changed depending on the ambient temperature and humidity, activity, and duration of work being performed.

The equivalent knowledge of WBGT limits for law enforcement personnel’s safety when wearing SBA is very limited, because there are no directly applicable standards for partially encapsulating protective equipment such as SBA which can cover more than 50% of the body surface area. Although both NIOSH and ACGIH have an obligation to protect individuals exposed to hot environments, current guidelines are based upon macro environmental WBGT, and with limited guidance for the additional heat stress from SBA.

The WBGT was devised by Yaglou and Minard,\(^{(6, 9)}\) to be used in open spaces with lightly clad individuals. Since its inception, it has been adopted widely for use for individuals wearing more encapsulating clothing and in more confined areas.\(^{(10)}\) Direct WBGT corrections for Level II SBA usage are not available. Estimations of the effect of SBA on WBGT suggest that SBA may add up to 5 °C to the WBGT in hot environments.\(^{(7, 11)}\) This adjustment has been suggested due to the additional weight of the SBA and the lack of evaporative and convective cooling that occur due to SBA being worn, but are not directly based on tests using SBA, and are therefore invalidated.

These factors, along with the exposure to moderately warm to hot environments, greatly increase the likelihood of heat injury, hypohydration, and reduced mental function. This situation requires that reasonably accurate predictions of heat stress be available for officer safety and for work planning. The lack of practical historical knowledge of heat stress in SBA in different work environments prevents accurate prediction of SBA heat stress. Characterization of the micro-WBGT under SBA for variable macro-WBGTs would allow creation of prediction
curves to predict micro-WBGTs under SBA which would permit use of extant work/rest NIOSH guidelines for workers in the heat.\textsuperscript{(10)}

The purpose of this study was to determine the effect of a moderate macro-WBGT environment (26 °C) compared to a previously tested (Ryan et al, 20xxb) hot macro-WBGT environment (30 °C) on microclimate (micro-WBGT) under a concealed Level II SBA during 60-min of moderately intense work. Additionally, a preliminary prediction model was developed to determine the effect of the heat on an individual wearing a concealed Level II SBA across time. It was hypothesized that compared to the hotter climate (macro-WBGT = 30 °C), the differences at a macro-WBGT of 26 °C would be greater, demonstrating the variable nature of the macro-micro difference.

**METHODS**

**Research design**

In the present study, participants underwent a single work trial in a moderately warm environment (WBGT = 26 °C). Previously collected data from our laboratory was used for the higher macro-WBGT (30 °C). (Ryan et al., 20xxb) The work trial matched the design of previous research collected in our lab (Ryan et al., 20xxb), with a non-modified, police standard issue Level II SBA worn underneath (concealed) a lightweight 65/35% cotton/polyester buttoned shirt. Participants worked until either: work trial was completed (60-min); $T_{re}$ exceeded 39 °C; heart rate exceeded 95% of maximum; evidence of heat stress (chills, nausea, confusion, etc.) presented; or volitional exhaustion was met.

Participants completed two sessions, a familiarization trial and one work trial, identical to the previous trial of Ryan et al. (20xxb) study, with the exception of the macro-WBGT
difference (26 °C vs. 30 °C). The work rate for the study trial of 300 Kcals · hr⁻¹ (1.05 L · min⁻¹ VO₂), was identical to the work/rest paradigm of the previous study (Ryan et al., 20xxb).

Participants

The study protocol was approved by the University Institutional Review Board, and written informed consent was obtained for all 9 male participants (age: 27 ± 4 yrs; ht: 180.0 ± 6.8 cm; wt: 79.8 ± 12.1 kg; body fat%: 14.9 ± 6.2%). All 9 participants had also completed a previous study (Ryan et al., 20xxb). All participants completed a Physical Activity Readiness Questionnaire and Health History Questionnaire to ensure health and physical readiness.

Familiarization Trial

Participants reported to the Human Performance Lab. Upon arrival, participants had all anthropometric measures taken and were introduced and fitted to the SBA. At the end of the familiarization visit, participants were instructed to refrain from heavy exercise, avoid alcohol, drink extra fluids (water), and to get at least 8 hr of sleep the night before the experimental trial.

Experimental Trial

Participants underwent one experimental trial in a moderately hot environment (WBGT = 26 °C). The experimental trial for this study was identical to the non-modified (control) trial of Ryan et al. (20xxb), with the exception of the macro-WBGT. Participants completed 60-min of total work at a rate of 300 Kcals · hr⁻¹, consisting of bouts of treadmill walking (12-min) and arm curls (3-min) followed by 5-min rest after 30-min of work.
Micro-WBGT measurements were monitored every minute using iButtons, a small combination temperature and humidity measurement devices (DS1923- Hygrochron, Embedded Data Systems, Lawrenceburg, KY) placed on the center of the front and back of the SBA carrier and data were uploaded upon completion of the work trial. All clothing and equipment in this study were matched to the same model of Ryan et al. (20xxb).

Statistical Analysis

An *a priori* power analysis revealed that a sample of 9 participants was sufficient to elicit an acceptable power (power = 0.80) to detect a mean difference of 0.19 °C in rectal temperature in a one-tailed test, using the standard deviation of ± 0.21 °C. Data are presented as means ± SD. Data were analyzed using SPSS v. 19.0 (SPSS, Inc., Chicago, IL).

A two-way repeated measures ANOVA (family-wise alpha set at 0.05) was conducted using the variables “temp” to denote the two macro-WBGTs (26 °C and 30 °C) tested, and “time” to indicate the five time points at which data was collected for analysis (0, 15, 30, 45, 60 min). Post hoc Bonferroni analysis and paired samples t-tests (Post-hoc adjusted alpha set at 0.01) were conducted for all significant interactions. Micro-WBGT under the front and back location were averaged for one micro-WBGT at each time point.

Due to the small sample sizes and the violation of assumption of sphericity in the “time” variable (Mauchly’s W(2) = 0.06, p ≤ 0.0001), all within-subject effects were analyzed using the Greenhouse-Geisser correction statistic.

A simple linear regression prediction model was established for both macro-WBGTs. The regression model was modified to include time points after the micro-WBGT plateaued at
the 30-min mark. The prediction model predicted mean micro-WBGT across time (categorical data \(1 = 30\)-min; \(2 = 45\)-min; \(3 = 60\)-min).

RESULTS

Nine participants completed the 60 min work bout trial at a macro-WBGT of 26 °C. The results from this trial were compared to a previously completed work bout at a macro-WBGT of 30 °C.

Two-Way ANOVA

Temperature

A significant main effect for the variable “temp” was observed, \(F(1.92, 9.58) = 21.02, p < 0.001\). Figure 1 represents the estimated marginal means of the micro-WBGTs measured under the SBA during the 60-min work bouts at the two macro-WBGTs tested. The micro-WBGT at the 26 °C macro-WBGT work trial was \(2.4 \pm 0.3\) °C cooler than the 30 °C work trial during the 60-min work trials. Mean micro-WBGT at the macro-WBGT of 26 °C (31.2 ± 0.2 °C) was 7% lower than the mean micro-WBGT at macro-WBGT of 30 °C (33.6 ± 0.1 °C).

Time

A significant interaction for the variables “temp x time” was observed, \(F(1.892, 15.132) = 33.426, p \leq 0.001\). Paired samples t-tests were conducted and noted that the 26 °C macro-WBGT condition maintained lower micro-WBGTs compared to the 30 °C macro-WBGT trial at the 15-min (\(p = 0.005\)), 30-min (\(p \leq 0.001\)), 45-min (\(p \leq 0.001\)), and 60-min (\(p = 0.001\) time
points. Figure 2 represents the mean micro-WBGTs of both macro-WBGTs tested for the five time points analyzed (0, 15, 30, 45, 60 min) during the 60-min work bout.

The most substantial increase in micro-WBGT was seen from the beginning of the work bout to the 15-min mark in both the 26 °C (11.9 ± 0.7 °C) and 30 °C (9.9 ± 0.4 °C) macro-WBGT work trials. Following this initial rise, micro-WBGT plateaued and increased only another 3-4 °C during the course of the next 45-min for both macro-WBGT trials.

**Linear Prediction Model**

Linear prediction models to predict micro-WBGT were created for each macro-WBGT tested. As Figure 2 indicates, micro-WBGT plateaus after the 30-min mark. Prediction models (Figure 3) were created using the last 30-min of the 60-min work bout to predict mean micro-WBGT at each macro-WBGT.

Micro-WBGT for both of the tested macro-WBGTs could be predicted across time. The derivation regression equations were: 26 °C: micro-WBGT = 0.4028(time) + 34.102, R² = 0.99; 30 °C: micro-WBGT = 0.4139(time) + 35.381, R² = 0.99.

**WBGT Adjustment**

As would be expected, micro-WBGT under the SBA was higher than macro-WBGT tested for each environment. The micro-WBGTs during the last 30-min of work were averaged and then compared to the macro-WBGTs at both trials. The averaged micro-WBGTs were 34.9 ± 0.6 °C and 36.2 ± 0.3 °C for the 26 °C and 30 °C macro-WBGT tested, respectively. As hypothesized, the mean differences were greater at the macro-WBGT of 26 °C compared to the 30 °C trial (p ≤ 0.001). The micro-macro difference was 8.9 °C at the macro-WBGT of 26 °C
and 6.2 °C at the macro-WBGT of 30 °C. This represents a 26% increase in micro-WBGT at the macro-WBGT of 26 °C and a 17% increase in micro-WBGT at the macro-WBGT of 30 °C.

**DISCUSSION**

The purpose of this study was to determine the effect of a moderate macro-WBGT environment (26 °C) compared to a previously tested (Ryan et al, 20xxb) hot macro-WBGT environment (30 °C) on microclimate (micro-WBGT) under a concealed Level II SBA during 60-min of moderately intense work. It is important to characterize the micro-WBGT under SBA in warm-to-hot environments so as to predict heat stress for Level II SBA users. Additionally, this study developed a preliminary prediction model to determine the effect of the heat on an individual wearing a concealed Level II SBA across time.

Previous studies have examined the effects of heat on individuals wearing various types of protective clothing.\(^{(7, 13-22)}\) Prediction models have been introduced to examine human performance and physiological responses to the heat,\(^{(23)}\) WBGT heat stress for outdoor environments,\(^{(24)}\) and attempting to establish WBGT adjustments for protective clothing.\(^{(7, 11)}\) The American Conference of Governmental Industrial Hygienists (ACGIH),\(^{(10)}\) has published threshold limit value (TLV) criteria and adjustments for individuals working in protective clothing in the heat.

The data show a sharp increase in micro-WBGT during the first 15-min of exposure to the macro-WBGTs tested in the current study. A nearly identical 33% rise in micro-WBGT occurred from 0 to 15 min at both of the macro-WBGTs tested. This rapid increase in micro-WBGT has been seen in other studies.\(^{(21)}\)
At the beginning of the 60-min work bout, the micro-WBGTs were lower than the macro-WBGT being tested; however, this may have been due to entering the chamber from a cooler environment. This is ecologically consistent with typical law enforcement use wherein officers leave a cool building or air-conditioned automobile before heat exposure. It has been established that micro-WBGT differences are more substantial at moderate macro-WBGT compared to higher macro-WBGT.\(^{(17-19)}\) The findings of the current study support previous indications\(^{(18)}\) that a smaller adjustment seems to be appropriate at higher temperatures.

These are the first WBGT adjustments to be directly applied for individuals wearing concealed Level II SBA. Our data suggest that a WBGT adjustment of ~10 °C is necessary to ensure the safety of individuals wearing concealed Level II SBA at the moderate macro-WBGT (26 °C) tested. The adjustment fell to approximately 6 °C at the tested 30 °C macro-WBGT. A number of different environments, higher and lower macro-WBGTs, and work intensities, should be tested to develop a stable prediction model of micro-WBGTs from various warm macro-WBGTs.

The regression suggest, based on the last 30-min of our 60-min test, that mean micro-WBGT can be predicted. Longer durations are needed to determine if this slope will be stable over longer time periods. It is important to note that at high macro-WBGTs (i.e. above 31 °C) the work/rest regimen for 300 Kcals · hr\(^{-1}\) are 25% work, 75% rest\(^{(6)}\) so very long extrapolations are not needed when macro-WBGT exceeds 32 °C at 300 Kcals · hr\(^{-1}\).

**CONCLUSIONS**

This research supports previous studies suggesting WBGT adjustments are needed due to micro-WBGT elevation are necessary for the formulation of safe TLV for individuals wearing
concealed Level II SBA. A WBGT adjustment of about 6-10 °C, depending on the macro-WBGT, may be necessary to ensure safety of the individual wearing a concealed SBA. Additionally, regressions for both macro-WBGTs tested appear to model well. However, the degree to which intensity of work play a role in affecting this correction has yet to be tested. Higher intensity workloads will elicit higher metabolic heat, and subsequent higher micro-WBGT. Therefore, until more testing is complete, a range of WBGT adjustments dependent upon macro-WBGT and work intensity appears to be the most accurate way to ensure the safety and comfort of an individual wearing a concealed Level II SBA.
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14 McLellan, T., M., Jacobs, I. & Bain, J., B. (1993). Continuous vs. intermittent work with Canadian Forces NBC clothing. Aviation, Space, and Environmental Medicine, 64, 595-598.


FIGURE 1. Mean micro-WBGTs for both macro-WBGTs tested during the 60-min work bouts. Mean micro-WBGT at macro-WBGT of 26 °C significantly lower than the 30 °C macro-WBGT. * Denotes significance at p ≤ 0.05.
FIGURE 2. Mean micro-WBGTs at the five time points analyzed (0, 15, 30, 45, 60 min) during the 60-min work bouts at both macro-WBGTs tested. Note the high increase in temp from beginning of the work bout (0 min) to 15-min time point. Following this initial rise, temp began to plateau and resulted in a 3-4 °C rise in micro-WBGT after the 15-min mark. * Denotes significant differences between MOD and CON conditions at p ≤ 0.01.
FIGURE 3. Modified linear regression of micro-WBGT at both macro-WBGTs (26 °C and 30 °C) over the last 30-min of 60-min work bout. Time was entered as categorical variables (1 = 30-min; 2 = 45-min; 3 = 60-min; etc.) in the regression equations.
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2008 TLVs and BEIs - Threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists (ACGIH).


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January 31, 2012

Gregory Ryan, ABD, CSCS
Department of Kinesiology
College of Education
The University of Alabama

Re: IRB Protocol # 11-028-ME
"Air Induction Cooling in Concealed Soft Body Armor in a Hot Environment"

Mr. Ryan:

The University of Alabama IRB has received the revisions requested by the full board on 12/13/11. The board has reviewed the revisions and your protocol is now approved for a one-year period. Please be advised that your protocol will expire one year from the date of approval, 12/8/11.

If your research will continue beyond this date, complete the Renewal Application Form. If you need to modify the study, please submit the Modification of An Approved Protocol Form. Changes in this study cannot be initiated without IRB approval, except when necessary to eliminate apparent immediate hazards to participants. When the study closes, please complete the Request for Study Closure Form.

Should you need to submit any further correspondence regarding this proposal, please include the assigned IRB application number. Please use reproductions of the IRB approved stamped consent/assent forms to obtain consent from your participants.

Good luck with your research.

Sincerely,

John C. Higginbotham, Ph.D., MPH
Medical IRB Chair
The University of Alabama
January 31, 2012

Gregory Ryan, ABD, CSCS
Department of Kinesiology
College of Education
The University of Alabama

Re: IRB Protocol # 11-029-ME
"Air Induction Cooling in External Soft Body Armor in a Hot Environment"

Mr. Ryan:

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The University of Alabama
January 31, 2012

Gregory Ryan, ABD, CSCS
Department of Kinesiology
College of Education
The University of Alabama

Re: IRB Protocol # 11-030-ME
“Effects of Macro-Environments on Microclimate Under Soft Body Armor During Moderate Physical Exertion”

Mr. Ryan:

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