Impact of Arm Immersion Cooling During Ranger Training on Exertional Heat Illness and Treatment Costs

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ABSTRACT Ranger training includes strenuous physical activities and despite heat mitigations strategies, numerous cases of exertional heat illness (EHI) occur. We developed an Arm Immersion Cooling (AIC) system that is not logistically burdensome and may be easily employed in training environments. Purpose: To examine the effect of AIC on EHI incidence, severity, and treatment costs during Ranger School. Methods: The training program was standardized for physical exertion and stress factors throughout the study period. AIC was used in the summer months of 2010–2012 (n = 3,930 Soldiers) and Control (CON; n = 6,650 Soldiers) data were obtained for summer months of 2007–2009. Descriptive characteristics of all EHI casualties were obtained, including hospitalization status (treated and released [Treat], evacuated [Evac] or admitted [Admit] to the hospital), which served as proxy indicator of illness/injury severity. Medical cost savings were calculated from hospital records. Results: Incidence rates were not different (CON 4.06 vs. AIC 4.00/1,000 person-days). Treat increased during AIC (18.43 vs. 4.84/1,000 person-days) accompanied by marked but non-significant decreases in Evac and Admit rates. AIC use was associated with a medical cost savings of $1,719 per casualty. Conclusions: AIC implementation during strenuous physical training in summer months can reduce EHI severity and associated medical treatment costs.

INTRODUCTION

Exertional heat illness (EHI) is a continuum of disorders from least severe heat exhaustion, to heat injury, and the most severe heat stroke.1 The impact of EHI on health can range from mild illness to prolonged hospitalization and ultimately death.1,2 EHI often occurs as the result of high ambient temperature and humidity conditions coupled with strenuous physical activity, wearing clothing/equipment and especially in combination with personal risk factors such as poor physical conditioning and/or lack of heat acclimatization. Though the incidence of and risk factors for EHI have been well-documented in the scientific literature,2–4 EHI remains a serious problem for military service members as well as athletes (e.g., football players, runners) and various civilian occupational groups (e.g., firefighters, miners, factory workers, and farmers).5–7

Because EHI can adversely impact the health and operational readiness of military personnel in both training and combat, risk mitigation strategies have been incorporated into military doctrine8 and Army policy requires annual training regarding mitigation policy and procedures and proper treatment of EHI casualties. The risk management process involves identifying individual (fitness level, acclimatization status, hydration) and environmental factors (via the Wet Bulb Globe Temperature index) that increase EHI risk and implementing individual and organization control methods in order to reduce EHI incidence and/or severity.8 Despite these efforts, EHI continues to be a problem, as throughout the U.S. Department of Defense there are over 300 exertional heat strokes and over 2,000 other EHI each year.7 Lost duty time because of EHI can range from several days to many months or discharge from military service.9 Although the overall incidence rate is relatively low, the potential medical severity of EHI, especially in field or training environments, requires consideration of additional mitigation procedures.10

Use of existing commercially available cooling solutions in military training or certain occupational settings presents particular challenges such as power requirements, transport and set up logistics, which limits their feasibility. Furthermore, these commercial systems are often costly, limited in their cooling power and the number of individuals that a single system can treat.11 Extremity immersion, specifically Arm Immersion Cooling (AIC), in cool or cold water has been demonstrated to be an effective body cooling method.12–14 Therefore, we developed a prototype AIC System for military and possibly civilian use in athletic field situations.11 Briefly, the AIC System consists of a water trough (cooled with an integrated thermometer and immersion time × water temperature chart in a lightweight, easily transportable package that presents minimal logistical demands. Over the past several years we have developed several prototype versions and there are currently approximately 100 AIC Systems...
distributed to numerous military training sites in the southern United States, including 25 concentrated at Ranger School at Fort Benning, Georgia. Subjective appraisal by the user community on the AIC System was very positive regarding reducing heat injuries, cardiovascular strain, perception of thermal stress, and ability to complete training activities. Further, this user community feedback is supported by published literature in this area\textsuperscript{11,12,14–16}; however, the effects of extremity immersion on reduction of EHI incidence, severity, and reduction in medical costs have not been assessed.

We were asked by the U.S. Army Training and Doctrine Command to evaluate the practice of AIC using an Army-designed prototype AIC System on the potential to reduce EHI incidence and severity as well as medical treatment costs in a military training environment. The purpose of this study was to examine the effectiveness of AIC on reducing EHI frequency and severity during summer months of Ranger School at Fort Benning, Georgia. To our knowledge, this is the first investigation to examine the impact of a cooling intervention on reducing EHI in a field training environment.

METHODS
We employed a retrospective study design using existing data from the Ranger Assessment Phase (first 4 days) of U.S. Army Ranger School. Ranger School is extremely physically demanding and is conducted at Fort Benning, Georgia, which has very hot (32–35°C) and humid (50–60% RH) summers. The U.S. Army Research Institute of Environmental Medicine Human Use Review Committee reviewed the protocol and determined that written informed consent was not required, as the data shared with the investigators were obtained from existing records and did not contain any information that identify an individual.

The U.S. Army Ranger School was provided with 25 AIC System prototypes in August 2010 and implemented the practice of AIC during the Ranger Assessment Phase (first 4 days) of all courses that started during the “heat season,” which encompassed mid-May through mid-September. School cadre provide the AIC System for use immediately following high-intensity training events and during rest periods, but the investigators did not have the ability to fully monitor their daily use, record the duration of use or monitor water temperature. The medical support staff was instructed to attempt to maintain AIC System water temperature within a temperature range of 10 to 20°C, and ice was provided with their deployment to keep temperatures within that range. Since August 2010, Ranger School cadre continued to use the AIC Systems during the Ranger Assessment Phase of training. All students who started Ranger School during August and September 2010 and May through September 2011 and 2012 comprise the experimental (AIC) group.

In order to calculate EHI incidence rates and estimate severity, injury data were obtained from Fort Benning’s Heat Injury Tracking reports. These reports are submitted by all tenant organizations on a weekly basis to note EHI casualties throughout the summer months. The control population (CON) consisted of students during the Ranger Assessment Phase of Ranger School summer classes during 2007–2009 and early 2010, before the 25 AIC Systems were made available. The Ranger Assessment Phase has been consistent regarding activities and heat strain countermeasures (except for AIC System use) during the control and intervention periods. Controlling for covariates such as environmental conditions and class size, a comparison of EHI casualties between the two time-frames would allow for the determination of the practice of AIC use on EHI incidence rates and severity. Heat Injury Tracking reports for all study periods were stripped of individual names before they were provided to the investigators. The data files included rank, date, and training activity at the time of an EHI incident, in addition to core temperature ($T_c$) data, as measured via rectal thermometer by an on-site health care provider, typically an Army medical service. Additionally, data were assessed regarding evacuation for further treatment to nearby Martin Army Community Hospital and whether the individual was admitted for further treatment.

In order to determine the possible effect of AIC implementation on EHI severity, hospitalization status was used as a proxy indicator of severity. Although International Classification of Disease (ICD)-9 diagnostic codes would have been preferred, it was not possible to obtain medical records. Acute care of an EHI casualty is provided at an on-site medical aid station and depending on the clinical judgment of the health care provider, a casualty may be transported to Martin Army Community Hospital for further care. It was assumed that casualties treated and released (Treat) at the Ranger School aid station were the least severe (i.e., heat exhaustion), those evacuated to the hospital (Evac), but not admitted likely had heat exhaustion or possibly mild heat injury, whereas those who were admitted (Admit) had the most severe EHI (heat injury or heat stroke).

Class size data were obtained from the Operations section of Ranger Training Brigade in order to calculate EHI incidence rates and account for variation in the number of students present for each class cycle; day-by-day student attrition data were used to calculate person-days. In order to quantify seasonal variability in ambient conditions, dry bulb temperature, wet bulb temperature and relative humidity data were downloaded from the National Climatic Data Center,\textsuperscript{17} using data recorded at the nearby Lawson Army Airfield weather station. For each EHI incident, the time of day when the injury occurred was not known; therefore the maximum dry bulb temperature for each date that corresponded with an incident was recorded. The wet bulb temperature and relative humidity that corresponded to the timepoint when maximum dry bulb temperature occurred were recorded as well. For non-casualties, the maximum dry bulb temperature for each of the 4 days was recorded and the mean was used for analysis. Similarly, the wet bulb temperature and relative humidity that corresponded to the timepoint when maximum
dry bulb temperature occurred for each of the 4 days was recorded and the mean was used for analysis. Black globe temperature data were not available, precluding calculation of the Wet Bulb Globe Temperature Index, therefore the Modified Discomfort Index (MDI) was calculated. Briefly, the MDI is calculated as $0.75 \times \text{wet bulb temperature} + 0.25 \times \text{dry bulb temperature}$ and the product is highly correlated with the Wet Bulb Globe Temperature Index ($r \geq 0.95, p < 0.001$) over several summers worth of observations.\textsuperscript{18}

We estimated the direct medical costs associated with treating EHI casualties using the Health Hazard Assessment programs Medical Cost-Avoidance Model.\textsuperscript{19} The system was queried to determine the outpatient and inpatient costs associated with all exertional heat exhaustion (ICD-9 codes 992.3, 992.4, and 992.5) and exertional heat stroke (ICD-9 code 992.0) cases treated at Martin Army Community Hospital during the study period. The average cost for treating heat exhaustion was calculated for the CON and AIC time periods, weighted by the number of cases per ICD-9 code per year. Weighted averaging was necessary as the number of cases, and costs per case, varied each year. Similar weighted averaging was conducted for exertional heat stroke costs and these data were used to estimate medical care cost savings. As ICD-9 codes were not available for the data in our sample, we applied the outpatient heat exhaustion cost to the Treat group and inpatient heat exhaustion care cost to the Evac group, whereas inpatient exertional heat stroke care costs were used for the Admit group. The proportional distribution of EHI casualties by severity during CON was applied to the number of casualties during AIC and the cost difference compared to the actual proportion during AIC was calculated. We assumed that the proportional distribution of EHI casualties in the Treat, Evac, and Admit categories before AIC implementation would have stayed the same had AIC not been made available.

### Statistics

A priori power analysis was conducted, assuming that AIC would reduce the EHI casualty hospitalization rate by half. Assuming approximately 3,600 subjects per group, 5 per 100 students EHI incidence and 95% confidence interval, the estimated sample power was 98%. Preliminary exploratory data analysis included analyzing EHI incidence rates before and after AIC implementation using a $\chi^2$ test, and the rate ratio was calculated as the AIC incidence rate over CON incidence rate. $\chi^2$ tests were also performed for each injury severity group. Dry bulb temperature, wet bulb temperature, relative humidity, and the MDI data were analyzed using independent sample $t$ tests. Core (rectal) temperature differences for each EHI severity grouping was analyzed with a 1-way analysis of variance with Tukey’s post-hoc tests when significant main effects were detected. It should be noted that any Ranger school student who suffered an EHI during or immediately following the physical fitness test on the morning of day 1 ($n = 47$) were excluded from the analysis. This is the first physical event of the course and the students had not been exposed to AIC yet; their first opportunity came immediately following this test. All descriptive data expressed at mean ± SD, and incidence rates are expressed per 1,000 person-days and severity is expressed as a percentage. All analyses were performed using SPSS v19.0; statistical significance was accepted at the $p < 0.05$ level.

### Results

The CON group consisted of 6,650 soldiers, 82 of whom suffered an EHI (4.00 per 1,000 person-days) whereas AIC consisted of 3,930 soldiers, with 46 suffering an EHI (4.06 per 1,000 person-days, $p = 0.93$ vs. CON) during the first 4 days of Ranger School. Overall incidence rate and incidence rate by severity data are presented in Table I. Implementing the practice of AIC increased the proportion of casualties in Treat by approximately 3.8-fold, with concomitant but statistically insignificant decreases in Evac and Admit. The proportional distribution of EHI by severity is shown in Figure 1. Rectal temperature at the time of EHI incident was significantly different between EHI severity groups (Admit vs. Treat during AIC only $[40.0 \pm 2.0 \text{ vs. } 38.7 \pm 0.8^\circ \text{C}]$, respectively, $p < 0.01$; Fig. 2) but not between CON and AIC ($p = 0.25$).

### Table 1. Overall EHI Incidence Rate and Breakdown by Severity Category

<table>
<thead>
<tr>
<th>Severity Category</th>
<th>CON</th>
<th>AIC</th>
<th>Rate Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>4.00</td>
<td>4.06</td>
<td>1.015</td>
</tr>
<tr>
<td>Treat</td>
<td>4.84</td>
<td>18.43*</td>
<td>3.807</td>
</tr>
<tr>
<td>Evac</td>
<td>2.19</td>
<td>1.41</td>
<td>0.643</td>
</tr>
<tr>
<td>Admit</td>
<td>1.31</td>
<td>0.77</td>
<td>0.60</td>
</tr>
</tbody>
</table>

*Treat, treated and released at the aid station; Evac, evacuated but not admitted to the hospital; Admit, admitted to the hospital. *Statistically significant vs. CON, $p < 0.01$.

### Figure 1. Proportion distribution of EHI casualties during the CON and AIC time periods. The proportion of casualties treated and released increased approximately 3.8-fold whereas those transported and/or admitted to the hospital were each reduced approximately 40%.

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Rectal temperature data were not available 4 casualties in the AIC group.

Environmental conditions during CON and AIC are summarized in Table II. Although dry bulb temperature was significantly higher and relative humidity significantly lower during AIC vs. CON, wet bulb temperature was similar and therefore overall thermal stress during AIC and CON was not different, as indicated by the MDI. Table III contains medical treatment cost calculations and estimated savings because of reduced EHI severity. Based on actual direct treatment cost data from the local Army hospital, EHI treatment costs during AIC were $134,843. Assuming that the proportional distribution of severity had been the same as during the CON period, we estimate that direct treatment costs would have been $213,896, or $79,053 more than actual costs over the 3-year period when AIC was implemented. As there were 12 class cycles and 46 EHI during the AIC study period, this represents direct medical care cost savings of $6,588 per cycle or $1,719 per EHI casualty.

DISCUSSION

Soldiers train in hot environments and there are currently few physical interventions available to reduce physiological strain and perhaps reduce heat illness incidence rates and/or severity. We developed AIC System prototypes that could be used coincident with hot weather military training and likely could be employed in occupational scenarios (firefighting) or summer athletics such as football or soccer practice/games. AIM has been demonstrated to be effective in removing body heat and we have received excellent anecdotal feedback from the user communities on our fielded 100 prototype AIC Systems. Based on these anecdotal reports, we sought to collect empirical data regarding the efficacy of AIC during Ranger training. To that end we conducted a large retrospective epidemiological study to experimentally determine if AIC reduced incidence rates, severity, and costs associated from EHI during physically demanding summer military training. Our data suggest that AIC reduced EHI severity, as the incidence rate and proportion of EHI treated and released at the Ranger school aid station increased approximately 3.8-fold after the practice of AIC was initiated (Table I, Fig. 1). The decline in the incidence rate and proportion of EHI in the Trans and Admit groups trended towards significance ($p = 0.13$ and $p = 0.18$, respectively). In addition, these benefits substantially reduced estimated medical treatment costs (Table III). To the best of our knowledge, this is the first study to examine a cooling intervention and the only study since the pioneering work of Yaglou and Minard on the WBGT index to demonstrate a relation between physical activity intervention and EHI incidence rates and severity.

Most epidemiological studies of EHI incidence and/or severity are retrospective and do not include an intervention. We had provided Ranger School with 25 AICS in 2010, enabling us to conduct this retrospective/intervention study when requested by U.S. Army Training and Doctrine Command in late 2012. However, we could not conduct a controlled matched study simultaneously, as AICS use was well received and concerns were that Soldiers would be placed at greater risk and mission readiness would be deterred without AIC use. This field study was conducted in an aggressive and physically demanding environment that routinely has EHI casualties during warm weather months. Controlled laboratory studies are rightfully constrained by ethical and human use guidelines that all but eliminate the occurrence of an EHI as a possible outcome. As a result, laboratory studies operate under the assumption that an intervention that limits the rise or augments the fall in body temperature and cardiovascular strain translates to decreased risk of EHI.

With the exception of Treat vs. Admit during AIC (Fig. 2), there were no differences in rectal temperature between groups. In addition to the known effects of extremity immersion cooling on core temperature, local and mean body skin temperature are reduced. Additionally, ratings of thermal comfort and of thermal sensation, which are heavily influenced by skin temperature, are improved. As mean skin temperature declines more rapidly than core temperature, as shown by Selkirk et al., it is plausible to speculate that brief periods of arm immersion may improve an individual’s thermal comfort before there is an appreciable decrease in core temperature. This may lead to a disconnect between behavioral and physiological thermoregulation and

![Figure 2](https://example.com/figure2.png)

**FIGURE 2.** Rectal temperature at time of EHI incident. *p < 0.05 between AIC Treat and AIC Admit groups.

![Table II](https://example.com/table2.png)

**TABLE II.** Environmental Conditions During the CON and AIC Periods

<table>
<thead>
<tr>
<th></th>
<th>CON</th>
<th>AIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry bulb temp</td>
<td>31.4 ± 3.3</td>
<td>33.5 ± 2.8*</td>
</tr>
<tr>
<td>Wet bulb temp</td>
<td>23.7 ± 3.2</td>
<td>23.3 ± 2.3</td>
</tr>
<tr>
<td>Relative Humidity (%)</td>
<td>52 ± 16</td>
<td>42 ± 12*</td>
</tr>
<tr>
<td>MDI (°C)</td>
<td>25.6 ± 2.9</td>
<td>25.8 ± 2.1</td>
</tr>
</tbody>
</table>

*Statistically significant vs. CON, $p < 0.01$.
TABLE III. Estimated treatment costs and cost savings during AIC

<table>
<thead>
<tr>
<th>Cost/medical encounter</th>
<th>Actual cost</th>
<th>Estimated encounters</th>
<th>Estimated cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treat</td>
<td>$216</td>
<td>$176</td>
<td>$987</td>
</tr>
<tr>
<td>Evac</td>
<td>$3,024</td>
<td>$4,327</td>
<td>$109,050</td>
</tr>
<tr>
<td>Admit</td>
<td>$5,000</td>
<td>$6,878</td>
<td>$103,858</td>
</tr>
<tr>
<td>Totals</td>
<td>$273,231</td>
<td>$343,843</td>
<td>$213,895</td>
</tr>
</tbody>
</table>

The cost/medical encounter data are actual health care costs retrieved from the Medical Cost Avoidance Model; see Methods for full details. By calculating the difference between the total actual cost during AIC and the estimated cost had AIC not been implemented, we were able to estimate medical treatment cost savings associated with AICS use ($79,053).

A possible increase in EHI incidence as well as higher core temperature at the time of injury, as individuals may continue working when core temperature is already dangerously elevated. Our EHI incidence and rectal temperature data do not support this possibility.

The U.S. Department of Defense maintains numerous databases that are useful for epidemiological investigations, such as the Defense Medical Surveillance System. However, many students attending Ranger School are there on a temporary basis, making it difficult to retrospectively identify those injured during Ranger Training, as demographic data would reflect their home duty station and hospital data may not reflect the activity or geographic location when injury occurred. The Fort Benning-specific Heat Injury Tracking report alleviated this problem, though it was not without limitations. Due to the lack of ICD-9 codes in the Heat Injury Tracking reports, we used hospitalization status as a proxy indicator of injury severity. Although we are confident that those treated and released at the Ranger School aid station were not cases of heat injury or heat stroke, it is possible that some of these cases were fluid-electrolyte imbalances (e.g., hyponatremia and hypohydration) and not heat exhaustion. Additionally, some heat exhaustion cases may have been transported to the hospital as a precautionary measure because of the judgment of the Ranger School clinician. We believe that the Ranger School standard operating procedure for treating EHI casualties, which was not revised during the 6-year course of this study, helps to mitigate this limitation and contributes to the consistency of the Heat Injury Tracking report database. Additionally, only 3 physician assistants served as head clinician at Ranger School during the 6-year study period, limiting the impact of variability in clinical judgment of injury severity on data quality, and the investigators maintained contact with them during the overlap and transition from one clinician to the next, in order to help ensure continuity in AIC implementation.

Extremity cooling will lower core and skin temperatures and reduce cardiovascular strain. Serious heat illness has complex physiological mechanisms but elevated core, skin temperatures and cardiovascular strain are likely physiological mediators of EHI. There is a growing body of literature concerning the efficacy of extremity immersion in cool water for heat stress mitigation, as we have recently reviewed. Prior studies reviewed used water bath temperatures between 10 and 30°C. Based on anecdotal observations made by the first author during site visits over the course of the AIC period, water bath temperature was usually between 2 and 20°C but was difficult to standardize because of remote locations and variability for logistical support. The lower water bath temperatures, 2 to 4°C range, were because of a considerable proportion of ice in the water trough. During CON, dry bulb temperature averaged 31.4 ± 3.3°C and relative humidity was 52 ± 16%. In contrast, during AIC, dry bulb temperature averaged 33.5 ± 2.8°C and relative humidity was 42 ± 12%, which was statistically warmer and drier than during CON ($p < 0.01$). Globe temperature data are unavailable, making it impossible to calculate the Wet Bulb Globe Temperature index during AICS or CON. However, utilizing the MDI as suggested by Moran and Pandolf, which is highly correlated with the Wet Bulb Globe Temperature index ($r > 0.95$), we were able to compare the ambient conditions in this study with the figure of Lind that describes compensable vs. uncompensable heat loss. Assuming that many physical activities during Ranger School are moderate to high intensity (400–600W); we believe that the environmental conditions during summer Ranger School classes often lie to the right of the prescriptive zone. Given the diminished dry heat loss capacity and increased reliance on evaporative heat loss, coupled with moderate relative humidity, under these conditions, it is prudent to explore means of providing active cooling.

A unique aspect of this study is the estimation of medical cost savings associated with AIC implementation. Heat exhaustion is primarily a cardiovascular event, whereas heat injury demonstrates end organ damage and heat stroke can have marked central nervous system and organ damage. Therefore, heat injury and heart stroke impose greater hospital costs and manpower reductions than heat exhaustion. We estimate the difference in direct medical care costs, which equaled $79,053 during the 3-year AICS use period. The Ranger training program has a relatively small number of students as opposed to the overall installation population. The most recent data indicate that over the last 5 years, there has been an average of 254 reportable EHI per year at Fort Benning. If we extend the per-casualty direct medical care cost savings estimate to the entire installation, annual cost savings associated with AIC implementation would be...
approximately $436,000. The U.S. Army return-to-duty policy for exertional heat stroke casualties is dependent on clinical severity, therefore we did not attempt to estimate the financial cost of lost duty time and instead focused on direct medical care costs. It is important to note that these cost savings are simply from a redistribution of injury severity among 46 casualties at a single course; the U.S. Department of Defense experiences over 2,300 EHI annually, suggesting a significant fiscal side-effect of providing an active cooling solution in the field training environment during periods of high heat stress.

This study is not without its limitations. The 25 AIC units were provided to Ranger School with recommendations regarding timing and use with respect to particular training events. Although the investigators maintained regular contact with Ranger School health care providers in order to ensure that the AICS were still being utilized, we did not have the ability to dictate the timing or duration of AIC use for Ranger School students. As a result, we do not have data documenting how often AIC was utilized and by how many students, water temperature during use or duration of immersion. However, we were assured by the Ranger School medical staff of AIC regular and consistent use. Additionally, the physical demands of Ranger School are unique, limiting the generalizability of our findings to other military schools/training environments or sports/occupational medicine situations.

Our study was the first to examine the effectiveness of a physical intervention to reduce heat strain during vigorous physical training in summer field conditions. EHI incidence rates were not different between AIC and CON (4.06 vs. 4.00 EHI per 1,000 person-days, \( p = 0.93 \)). AIC increased the Treat group (0.15 vs. 0.53%, risk ratio 3.54) accompanied by marked but nonsignificant decreases in the Evac and Admit cases. EHI use was associated with direct medical care cost savings of $79,053 over 3 years, or $1,719 per casualty, for treatment of EHI during Ranger training. We conclude that AIC should be considered for sports/occupational medicine use to reduce severity of EHI in field situations.

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REFERENCES