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Aluminet: An Intervention for Heat-related Illness among Construction Workers

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Aluminet: An Intervention for Heat-related Illness among Construction Workers

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ABSTRACT

The objective of this study was to evaluate the efficacy of a new form of personal protective equipment (PPE), reflective Aluminet vests, designed to reduce exposure to environmental heat stress and associated heat-related illness (HRI) among construction workers. Trained observers shadowed fifteen (15) healthy construction and landscape workers for two workdays under hot and humid conditions. Participants wore an Aluminet vest on one day and a conventional work vest on the other. Presentation of the work vests was randomized and counterbalanced to prevent order effects, and working conditions (i.e., work activities, weather, etc.) were matched as closely as possible. Direct measurements of core body temperature, skin temperature, heart rate, and intensity of occupational physical activity were assessed using reliable, valid, and precise field measurement methods, with minimal employer burden. Self-reported estimates of perceived exertion, fatigue, and thermal comfort/discomfort were also collected.

KEY FINDINGS

- Aluminet vests (50% weave) were not observed to have a statistically significant effect on summary metrics collected during construction work relative to the conventional vest.
- Participants reported less total fatigue, lethargy, and body ailment after wearing the Aluminet vest relative to after wearing the conventional vest; however, these effects were not statistically significant.
- The project yielded valuable insight for the construction safety and health research community about strategies for working with outdoor workers exposed to heat. For example, alternative direct measurement technologies to core temperature pills should be developed and explored in future work due to challenges encountered with their potential use in this study.
- While the Aluminet vests trialed in this pilot study were highly visible and reflective, concerns regarding the color of the vest required the use of high-vis, “safety” colored bands in addition to the vests themselves. Future work should ensure that intervention materials are of a high-vis color to promote acceptance from stakeholders.
- Participants were generally interested in the use of the direct measurement technologies (e.g., heart rate monitors, temperature sensors, etc.) to collect relevant exposure information. Smart sensor technologies may hold promise for future work in the construction sector.

INTRODUCTION

Environmental heat exposure and associated heat-related illness (HRI) is a common occupational health and safety problem.[1, 2] Each year, HRI accounts for approximately 658 fatalities in the United States[3] and contributes to many other deaths that are categorized as other conditions (e.g., myocardial infarction).[4] The construction industry is particularly susceptible to environmental heat exposure and HRI.[4-7] During an 11-year period (1995–2005) in Washington State, an analysis of workers' compensation claims for HRI indicated that HRI claim incidence rates by industry sector were highest in the construction sector at 12.1 claims per 100,000 full-time equivalent (FTE) workers.[8] Moreover, from 2000–2010, the US Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI) identified 359 worker deaths that were attributed to heat exposure, contributing to a yearly average fatality rate of 0.22 deaths per 1 million workers.[4] The construction industry had the second highest annual rate of heat-related mortality at 1.13 deaths per 1 million workers (5 times the average rate). The magnitude of the problem is exacerbated in the Southeast region of the United States where high humidity levels increase worker risk of HRI.[9]

Although an abundance of guidance is available on the best practices for preventing occupational HRI (e.g., International Organization for Standardization ISO7243[10]; American Conference of Government Industrial Hygienists [ACGIH] permissible heat exposure threshold limits values [TLVs][11], etc.), effective interventions for combating HRI are lacking. Many forms of personal protective equipment (PPE) designed to improve the visibility of workers, such as reflective vests, are often constructed of impermeable materials that prevent effective heat dissipation; increasing worker risk of heat strain.[6] Management of heat stress, therefore, has traditionally been based on monitoring the environment and training workers to employ protective behaviors (administrative controls) such as hydration and self-pacing.[7, 12, 13]

Aluminet is a mesh material made from a metalized high-density polyethylene (HDPE) thermoplastic. Typically used in greenhouse settings, Aluminet has been shown to reduce greenhouse temperatures by 9 - 14%[14] and to improve the growth and quality of plants.[15-18] The material is durable and can be cut and sewn at any angle with no fraying or damage to the cloth under normal use.[19] It is also reflective, not electrically conductive, and is safe for wearing. Used as a reflective vest, Aluminet may greatly improve efforts to reduce the potential for HRI and protect construction worker health and safety. No previous study, however, has evaluated the efficacy of reflective Aluminet vests as an intervention for reducing exposure to environmental heat stress among construction workers.

OBJECTIVE

The objective of this study was to evaluate the efficacy of reflective Aluminet vests as an intervention for reducing exposure to environmental heat stress among construction workers.

METHODS

Study Sample

Study participants were a convenience sample of 7 healthy poured-concrete foundation workers employed by a major construction firm, and 8 healthy university landscaping and builiding maintenance workers. All participants reported 1) being between 21 and 50 years of age, 2) no history of physician-diagnosed cardiovascular disease, 3) no history of a physician-diagnosed neurodegenerative disorder that may affect movement (e.g., Parkinson's Disease, etc.), and were 4) acclimated to working outside in a hot environment. Acclimation was defined as having worked at least 7 days in the heat during the summer and/or having been reacclimated to the heat for 4 days if recently absent from the heat for 2 weeks, 5 days if recently absent from the heat for 4 weeks, and 6 days if recently absent from the heat for 6 weeks. Institutional Review Board approval of all study procedures was obtained from Auburn University and each participant provided written informed consent.

Experimental Procedure and Data Collection Instruments

Each participant was measured for two workdays under hot and humid conditions (at least 30°C / 85°F, 60% relative humidity). Participants wore an Aluminet 50% weave vest that covered the torso for one day (Figure 1).

A 50% weave alleviates 50% of the radiant heat load (i.e., reflects radiant heat from the sun back into the environment, rather than absorbing it). For the other day, participants wore a conventional work vest. A similarly colored and constructed shirt was worn under the vests on both collection days. Data collection took place on consecutive days for each participant. The poured-concrete foundation workers were observed while on a construction site in Birmingham, AL, while the landscaping and building maintenance workers were observed while on the Auburn University campus. Presentation of the vests was randomized to prevent potential order effects. A trained observer recorded the time (to the nearest minute) for the specific activities being performed by each worker to account for any potential differences in work (e.g., tasks performed, sunlight vs. shade, operating hot equipment, etc.).

Figure 1. Poured-concrete foundation workers wearing the Aluminet and conventional vests during work.

Core Body Temperature

Core body temperature was assessed once every 30 minutes using a digital tympanic (i.e., ear) thermometer (Braun Thermoscan, Aschaffenburg, Germany) following manufacturer directions.

Heart Rate and Occupational Physical Activity

Continuous measurement of heart rate (HR) was sampled at 30 Hz using a HR monitor (Polar™) that was paired directly with a physical activity monitor worn on the dominant hip (ActiGraph, Pensacola, Florida, USA). Raw acceleration information from the physical activity monitor was transformed to reflect metabolic equivalents (METs) expressing the energy cost of physical activities following the recommendations of Sasaki et al., 2011 [20].

Skin Temperature

A Thermochron iButton® thermistor (DS1921H, Maxim/Dallas Semiconductor Corp., USA) was secured to the HR monitor strap and placed directly on the skin to measure skin temperature once per minute during each work shift. The device is accurate to ±1 °C at a resolution of 0.125 °C, and has been observed to be reliable in several studies.[21-23]

Self-Reported Exertion, Fatigue, Thermal comfort/discomfort, and Wetness

Perceptions of effort, fatigue, thermal comfort/discomfort, and wetness as a result of work using Borg's Rating of Perceived Exertion (RPE) Category Ratio (CR) 10 Scale,[24, 25] the Fatigue Assessment Scale for

Construction Workers (FASCW),[26] and 10cm visual analog scales (VAS),[27, 28] respectively. The Borg RPE Scale is a widely used, uni-dimensional scale designed to assess subjective assessment of whole body exertions.[24, 25] Responses to the scale range from 0 (nothing at all) to 10 (very, very strong) with several verbal anchors provided to increase usability.[29] The Borg RPE scale is reliable and valid, and correlates well with a variety of physiological measures (e.g. HR, ventilator drive, blood lactate concentration, etc.) and psychological measures.[30, 31] Participants completed a Borg CR10 every time that core body temperature was assessed.

The FASCW is a 10-item fatigue assessment scale that was designed to assess the severity of fatigue among construction workers.[26] The FASCW consists of two sub-scales ("Lethargy" and "Bodily Ailment") with demonstrated internal consistency, acceptable test-retest reliability, and substantiated concurrent, convergent, and divergent validities. Participants completed the FASCW immediately following their shift.

Environmental Conditions

Measurements of the ambient temperature and relative humidity were collected using a 3M™ WIBGET™ Heat Stress Monitor (WB-300) at approximately the same time that core body temperature was assessed for one participant each collection day. Maximum daily temperatures were also obtained for each workday from the National Oceanic and Atmospheric Administration (NOAA) site in closest proximity to the data collection site.

Statistical Analysis

Summary measures (mean and standard deviation [SD]) for each participant across each workday were calculated. Standard analytic tests for the normality of the distributions (i.e., Shapiro-Wilk) were then performed. Descriptive analyses of the distributions (mean, SD, and coefficient of variation [CV] for parametric data; median and interquartile range [IQR] for non-parametric data) of the primary summary measures were developed for each experimental condition (Aluminet vs. conventional vest) based on the results of the tests of normality. Paired t-tests (2-tailed) were then used to estimate the effect of experimental condition on each of the summary measures for the parametric data. The Wilcoxon signed rank test was used for self-reported fatigue estimates and continuous summary measures that were considered non-normal following a statistically significant (p <0.10) Shapiro-Wilk Test of Normality. Comparisons were planned apriori; therefore, no adjustment was made for multiple comparisons (i.e., each comparison was evaluated for statistical significance using a p-value of 0.05). All statistical analyses were conducted with IBM SPSS Statistics, version 23 (IBM Corp., Armonk, NY, USA).

RESULTS

Descriptive statistics for each of the primary summary measures including weather and workload conditions observed for each experimental condition is included in Table 1. Participants were observed for an average of 8.4 hours in hot and humid conditions (median average measured Wet Globe Bulb Temperature [WGBT] outdoor Temp of 85.5 °F, median average measured relative humidity of 50%, and average measured maximum temperature of 92.3 °F). Work tasks completed by the participants varied and included activities such as laying concrete, constructing wooden supports, lifting/carrying heavy objects, raking, laying sod, among others. Despite the array of activities observed across participants, the majority of the work tasks performed were consistent within participants and between experimental conditions as evidenced by the absence of statistically significant differences of workload. For example, participants burned an average of approximately 1000 kcals each day while spending approximately 20% of their time engaging in moderate or vigorous physical activity (Percent time in MVPA) regardless of experimental condition.

Participants reported less total fatigue, lethargy, and body ailment after wearing the Aluminet vest (FACSW total score = 13.8 ± 5.2, lethargy = 7.7 ± 3.5, body ailment = 6.1 ± 1.9) than after wearing a conventional vest (FACSW total score = 15.2 ± 6.0, lethargy = 8.4 ± 3.9, body ailment = 6.8 ± 2.3). Additionally, HR estimates were reduced when wearing the Aluminet vests (105 beats per minute [BPM]) in comparison to when wearing the conventional vests (110 BPM). However, these effects were not statistically significant. Additionally, no statistically significant effects were observed for core body temperature, skin temperature, or self-reported estimates of thermal comfort/discomfort and wetness.

Table 1. Mean (SD) and Median (IQR) of relevant summary metrics by vest condition.

	Aluminet		Conventional		
Summary Measure	Mean	SD	Mean	SD	p [a]
Time Observed (Hours)	8.40	0.67	8.45	0.72	0.74
Kilocalories Burned	1014.57	455.55	1094.43	537.95	0.41
METS	1.53	0.45	1.52	0.34	0.94
Percent Time in MVPA	19.11	8.35	19.59	8.51	0.80
Heart Rate (BPM)	105.01	21.54	110.23	16.93	0.06
Skin Temperature (°F)	93.16	2.28	93.42	2.08	0.44
Wetness VAS	3.62	2.96	3.74	2.60	0.81
Average Borg Rating	2.16	0.96	2.27	0.88	0.34
	Median	IQR	Median	IQR	p [b]
WGBT Avg. Outdoor Temp	85.48	8.79	85.48	11.53	0.13
WGBT Avg. Relative Humidity	50.00	2.00	48.75	2.52	0.25
WGBT Outdoor Max Temp	92.30	7.70	92.30	9.45	0.80
NOAA Max Temp	91.00	5.00	91.00	4.00	0.84
Core Temperature (°F)	98.53	0.88	98.47	1.14	0.78
Thermal Discomfort VAS	1.33	3.72	1.40	2.72	0.83

[a] *p*-values obtained from Paired t-tests

[b] *p*-values obtained from Wilcoxon Signed Rank tests following significant (p <0.10) Shapiro-Wilk Test

PRACTICAL IMPLICATIONS

Very few interventions for preventing HRI among construction workers currently exist. The American Conference of Government Industrial Hygienists (ACGIH) has published threshold limit values (TLVs), establishing a recommended acceptable limit of heat exposure that can be tolerated in an occupational setting (ACGIH, 2006). The TLVs and other guidelines, however, are considered by many to be too conservative [32] and, therefore, may be impractical. Additionally, there is currently no standard for PPE to prevent HRIs in construction workers and relatively few studies have explored PPE-based intervention strategies, particularly at real construction sites.[32]

Despite encouraging reports of less total fatigue, lethargy, and body ailment, results of this field-based study suggest that the Aluminet vests were not an effective intervention for reducing exposure to environmental heat stress. Although the Aluminet vests were not observed to be an effective solution, PPE interventions may still be an effective approach. Yi et al. (2017) examined the efficacy of a cooling vest made of hybrid materials designed to help to ventilate around the body and prevent HRI. Trials concluded that the technology was successful in maintaining lower core and skin temperatures during physical work than conventional vests.[33] Additionally, a novel construction uniform made of lighter and thinner materials with improved thermal and moisture properties as compared to a standard construction uniform has also been evaluated by the same investigators.[34] Additional research on garments that may reduce the risk of HRI among construction workers is warranted.

In addition to PPE and cooling garments, other interventions may be fruitful. Yi et al. (2016) proposed a risk management system that used a prediction model based upon HR data as a more objective indicator of heat strain.[35] Early warning systems based upon smart sensor technologies such as that proposed by Yi et al. may be easy to use and implement; however, additional research is necessary to demonstrate their effectiveness. Of course, conventional methods for reducing environmental heat exposure and preventing HRIs such as promoting self-paced work, hydration, and rest is critical while additional interventions are studied.[36, 37]

PROBLEMS RESULTING IN MODIFICATION OF PROPOSED METHODS AND OTHER LIMITATIONS

Several challenges arose during performance of this study:

1. The employers of the participants in this study expressed concerns regarding employees ingesting CorTemp temperature sensors. Specifically, the concerns were that an employee may i) incorrectly attribute negative consequences of an unforeseen and unrelated medical condition to swallowing of the pill placing the employer at risk of liability, and ii) an emergency situation arising that required an immediate MRI that would not be possible because the employee ingested the sensor.

   To address this challenge, we used a digital tympanic (i.e., ear) thermometer to capture core body temperature after securing approval from CPWR and the Auburn University IRB. While tympanic core body measurements have been observed to have slightly greater variability than core body temperature measurements assessed rectally or using an ingested pill, they are considered "a good site for non-invasive core measurement of body temperature".[38] However, in practice it was difficult to obtain consistent readings in the field.

2. Concerns were expressed by the employers of the participants in this study regarding the color of the Aluminet vests. While the silver color was deemed highly visible by the partnering organizations, it was suggested that colored bands be added to the vests or that the vests be painted a high-vis "safety" color. To address this concern, reflective high-vis harnesses (Figure 1) were worn with the Aluminet vests, thereby not requiring modification (e.g., painting) of the Aluminet vest itself.

3. Temperatures in the state of Alabama did not reach 35°C / 95°F until the end of July. Production delays at the construction site also prevented access to potential participants until late in the summer. Given the limited number of sufficiently hot days for the originally proposed methods, the study team modified data collection criteria to be based upon the forecasted heat index. Specifically, a heat index of 80 degrees was used as the criteria for collecting data. It is unknown what effect the reduced temperature may have had on study results. It was hypothesized that the Aluminet vests would perform better than a conventional vest as exposure to high temperatures and associated environmental heat stress increased. Additional research of the use of Aluminet vests in extreme temperatures is warranted.

4. Work shifts for the landscaping and building maintenance workers were from approximately 5:00 a.m. to 1:30 p.m. The poured-concrete workers generally worked from approximately 6:00 a.m. to 3 p.m. The timing of the shifts helped the workers schedule the most intense work for the cooler parts of the day. Therefore, the vests may not have been evaluated during the hottest parts of the day. However, the within-subject comparison limits the potential negative effects that this limitation may have caused.

FUTURE FUNDING PLANS

Overall, this research offered a "high reward" opportunity. The reflective Aluminet vests were an innovative potential solution not previously evaluated for use as a vest among workers. While the results of this study suggest that Aluminet vests may not have a statistically significant effect on several summary metrics during construction work relative to the conventional vests, Aluminet may be more effective when applied in an alternative format. For example, Aluminet shade tents may be an inexpensive approach to providing relief from the heat for construction workers. The research team will continue to explore the use of Aluminet in different forms. If a practically meaningful difference is observed, future projects may be proposed to CPWR and other agencies.

PRESENTATIONS / PUBLICATIONS

1. Lusk*, C., Zhang, X., Badawy, M., Cressman, S., Sesek, R.F., Redden, L., Pascoe, D., Schall Jr., M.C. (Submitted). Aluminet: Investigating a potential intervention for preventing heat-related illness among construction workers. 7*th Annual Southeastern States Occupational Network (SouthON) Meeting*; 2018 April 5-6; Savannah, GA.

DISSEMINATION PLAN

A webinar recording was posted to the Deep South Center for Occupational Health and Safety website for all interested stakeholders to access at their convenience (Link: http://www.soph.uab.edu/dsc/aluminet-potential-intervention-heat-related-illness-among-construction-workers). The work was also presented at an Auburn / Montgomery Section Meeting of the American Society of Safety Engineers. An abstract for oral presentation of project results has been submitted to the 7th Annual Southeastern States Occupational Network (SouthON) Meeting. The research team intends to submit a proceedings paper for presentation at the 2018 annual meeting of the Human Factors and Ergonomics Society. Additional analyses are being explored to develop a journal publication. The research team will continue to work with CPWR's dissemination group to market this work to interested stakeholders.

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