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Cooling Interventions Among Agricultural Workers: A Randomized Pilot Study

By

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Doctor of Philosophy

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An abstract of
A dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
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Abstract

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Background: Adverse health effects among agricultural workers due to chronic heat exposure have been characterized in the literature as not only due to high ambient temperatures but also due to intensive manual labor in hot and humid conditions. The US Centers for Disease Control and Prevention reports that the average annual heat-related death rate among agricultural workers is nearly 20 times greater than that of the overall US workforce. This study builds on the *Girasoles* Study, initiated in 2014 in partnership with the Farmworker Association of Florida (FWAF) in response to the Florida agricultural community's ongoing concerns about the impact of chronic heat exposure on their health.

Methods: In April-May of 2018 and 2019 we conducted pilot studies in Florida, to examine workplace personal cooling gear interventions that could prevent HRI. A sample of 84 agricultural workers in Florida were randomized to 1 of 4 groups: 1) no intervention, clothing as usual; 2) cooling bandana; 3) cooling vest; and 4) both the cooling bandana and cooling vest. Biomonitoring equipment worn by the participants included core body temperature and heart rate monitor belts, and an accelerometer to capture physical activity.

Results: A total of 78 agricultural workers completed one intervention workday. Core body temperature differences were observed; the bandana group had 38% of participants exceeded 38.0°C, followed by 46% in the control group, 53% in combination group, and the vest group had the highest proportion with 60%. Logistic regression analysis revealed the bandana group had lower odds of exceeding a core body temperature of 38.0°C (OR 0.7, CI90 [0.2, 3.2]) and the vest group had higher odds of exceeding 38.0°C (OR 1.8, CI90 [0.4, 7.9). The use of both the cooling vest and bandana (combination group) showed the effect was little different from the control group (OR 1.3, CI90 [0.3, 5.6].

Conclusion: This is the first field-based study to pilot cooling intervention among agricultural workers in the US using biomonitoring equipment. This study found that agricultural workers that used a bandana while working in a hot environment has the potential to be protective against exceeding a core body temperature of 38.0°C.

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Dedication

This dissertation is dedicated to my mom, Maria Del Carmen Chicas.

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Table of Contents

Chapter 1: Introduction

Problem Statement

The years of 2014-2018 were the warmest years in modern record.[1] The mean global temperature is predicted to rise 3-4 degrees Celsius by the end of the century.[2,3] This is of critical importance because with every degree Centigrade increase, mortality rates related to heat rise by 2-5%.[4] Heat waves, phenomena exacerbated by global climate change, pose an emergent global health risk.[5] Heat extremes are increasingly linked to negative health outcomes, including fatalities, heat exhaustion, and exacerbation of chronic conditions.[6] Agricultural workers are especially vulnerable to these rising temperatures as they perform intense labor outside in direct sunlight and often in conditions of high humidity, which can put them at increased risk for heat-related illness (HRI). The US Centers for Disease Control and Prevention (CDC) reports that the average annual heat-related death rate among agricultural workers is nearly 20 times greater than that of the overall US workforce.[7]

Heat-related illness occurs when the body's innate compensatory mechanisms for combating heat exposure, including evaporative cooling, are overburdened.[8] Symptoms of HRI include muscle cramps, nausea, dizziness, headaches, high body temperature, and heat stroke. The Occupational Safety and Health Administration (OSHA) is the federal agency in the US charged with educating agricultural workers and their employers on heat hazards, management of these hazards and early recognition of symptoms. OSHA has issued recommendations for the protection of workers in all hot work environments, primarily water, rest, shade. Unfortunately, agricultural workers often lack the ability to modify their work environments, may not have shade available to them, may not have access to adequate water in the fields, and— if paid according to volume harvested— may not want to take frequent work breaks.[9-11] These occupational factors place this population at increased risk for HRI.

In North Carolina, cross-sectional survey studies of agricultural workers reported one or more HRI symptoms in the previous week 72% (n=158),[12] previous 3 months 53% (n=68),[13] or ever experienced HRI symptoms 40% (n=281).[14] The proportion of agricultural workers in Georgia who reported one or more HRI symptoms was 71% (n=405).[10] Common symptoms reported were headaches, dizziness, nausea or vomiting and muscle cramps.[10,12,14,15] Studies in Florida have reported agricultural workers suffer from (HRI) and elevated core body temperatures that exceed the threshold at which workers should stop activities to rest and rehydrate. [10,14,16,17] The combination of high environmental temperatures and intense physical activity can result in rapid onset of exertional heat stroke and is associated with higher core body temperatures.[18] Core body temperature is maintained roughly at 37ºC. Once core body temperature reaches 38°C, heat exhaustion can ensue and can lead to heat stroke when core body temperatures reach or exceed 40ºC.[8] The National Institute for Occupational Safety and Health (NIOSH) and The American Conference of Governmental Industrial Hygienists (ACGIH) recommend that core body temperatures not exceed 38ºC in prolonged exposure to strenuous work (>2hours). The Occupational Safety and Health Administration's (OSHA) recommends workers drink water and rest every hour in the shade long enough to recover from HRI.[19] In addition, chronic dehydration, and acute kidney injury while laboring in hot and humid conditions have been observed.[10,14,16,17]

These findings have implications for agricultural workers' health and for their ability to recover from work-related heat stress after their work day, pointing to the increased risk factors of this occupational group. Only one worksite-based HRI interventional study has been conducted with agricultural workers, which was in in El Salvador,[20] and there has been one simulation study testing interventions with Korean agricultural workers.[21] A US workplace-based intervention study examining heat-adaptive interventions is timely, and greatly needed. Therefore, the purpose of this dissertation was to conduct a worksite-based intervention study with agricultural workers in Florida, randomized to examine individual and combined effects of multiple cooling gear.

Aims of Study

Building on prior research conducted in partnership with the Farmworker Association of Florida (FWAF), this current work seeks to examine personal cooling interventions that do not interfere with workers' daily working routine and have potential to help maintain core body temperature below the recommended physiologic limit of 38.0ºC (100.4ºF). Research exploring personal cooling interventions that help to maintain core body temperature under the recommended limits will provide the basis for evidence-based interventions and advance the science for the prevention of heat-related illness in this and other vulnerable worker populations. The overall goal was to determine which intervention (or combination of interventions) was practical to use while working, and the physiological response to using personal cooling gear among agricultural workers. This study uses a mixed methods approach that integrated qualitative and quantitative data to yield multi-dimensional understanding of the results. This goal was achieved through the following specific aims:

1. Determine the feasibility of utilizing a cooling bandana, a cooling vest, or both a cooling vest and a cooling bandana together;

   Objective 1. Determine participant acceptability of wearing cooling devices while working.

   Objective 2. Determine the practicality of maintaining the cooling effect of devices at work.

2. Determine the effect of these interventions on core body temperature and self-reported heat-related illness symptoms.

   Objective 1. Determine if core body temperature exceeds the threshold of 38°C by cooling device used.

Objective 2. Determine if using a combination of two cooling devices reduces the risk of exceeding the threshold of 38°C.

3. Determine the interrelationships of environmental temperature (ambient temperature and humidity from local weather networks), and personal vulnerability factors [dehydration (urine specific gravity), physical activity (actigraphy), age, sex, body anthropometrics (body fat, height, weight, waist/hip circumference)], and work characteristics.

Objective 1. Examine the influence of environmental heat exposure, personal vulnerability factors, and work characteristics on exceeding the threshold of 38°C while using cooling devices.

Background

Outdoor workers— especially those with physically demanding jobs that expose them to extremely hot temperatures— are identified as occupational groups at increased risk of heat stress and heat-related illness (HRI) associated with climate change.[6] Heat stress is the net heat load a worker is exposed to from combined factors such as metabolic heat, environmental factors, and clothing worn that contribute to increased heat storage in the body.[22] Exposure to a hot environment for a prolonged period while working can result in heat strain that debilitates the body's ability to cool itself, causing HRI and in severe cases heat-related death. Heat strain is the overall physiological response resulting from heat stress [22]. HRI is a preventable condition that exists along a continuum from less severe signs and symptoms such as muscle cramps to heat exhaustion and heat stroke.[8]

It is estimated that between 2-3 million[23] workers are employed in the US agricultural industry and are at risk of heat-related mortality that is 20 times greater than the general workforce population.[7] Yet, federal heat hazard regulations do not exist for preventing HRI in agricultural workers, despite disparities in heat-related mortality when compared to workers in other hot environments.[24] Only three states, California, Washington, and Minnesota have adopted specific heat exposure guidelines.[25,26]

The Occupational Safety and Health Administration (OSHA), as a federal agency, is tasked to create and enforce occupational safety laws that protects all employees. Section 5(a)(1) of the Occupational Safety and Health Act of 1970 states that employers are required to provide a workplace that "is free from recognizable hazards that are causing or likely to cause death or serious harm to employees." This general clause, however, does not provide specific federal protection standards against the hazards of occupational heat exposure nor does it require employers to have a heat protection plan implemented for their workers. Unfortunately, agricultural workers have little control over their work environments[11,27-29] and identification and implementation of effective cooling interventions to increase the safety of agricultural workers are needed. Occupational health and safety training, and access to water, rest breaks, and shade, are often inadequate.[15] If paid by a piece-rate system, i.e., paid by the number of units produced rather than by the hour, workers may be reluctant to rest or may be discouraged from taking work breaks since they may produce fewer units and thus receive a lower wage.

In 2011 OSHA launched a heat illness prevention campaign focused on *Water.Rest.Shade* to keep workers safe in the heat.[30] Despite the campaign, subsequent studies show workers continue to experience HRI at concerning rates.

Several studies have investigated the occurrence of HRI in agricultural worker populations in North Carolina, California, and Georgia, using self-reported HRI symptom questionnaires. A cross-sectional study of 300 agricultural workers in North Carolina found that 94% of the agricultural workers reported working in extreme heat and 40% reported having HRI symptoms.[14] A study of 467 agricultural worker households in Mendota, California reported that, while more than

90% of the workers indicated they had received training on HRI, their level of knowledge was only moderate.[31] One-third of 405 agricultural workers interviewed in Georgia reported they had experienced three or more heat-related symptoms during the preceding week. Most (77%) reported lack of training and no access to regular breaks, shade, or medical attention.[10] In a 2017 study of 588 agricultural workers in California's Central Valley, 8.3% experienced a core body temperature ≥ 38.5°C (101.3°F) in response to an average wet bulb globe temperature of ~31°C (~88°F); no description of symptoms was given.[32] These results reflect differences in regulation and demographic differences in the types of work, risks of heat exposure, levels of knowledge and/or training, and other factors between states. In addition to cross-sectional surveys, a study of the heat indices present in common and sleeping rooms in 170 North Carolina agricultural worker camps found dangerously high temperatures in most rooms, regardless of time of day.[33] These findings have implications for agricultural workers' health and for their ability to recover from work-related heat stress after their work day, pointing to the increased risk factors of this occupational group.

In a CDC-NIOSH-funded R01 research grant— The *Girasoles* Study by Emory University and in partnership with Farmworker Association of Florida (FWAF)— the physiological response of chronic heat exposure was assessed through real time biomonitoring of core body temperature. The study sample of agricultural workers has consisted to date of immigrants from Mexico, Central America, and Haiti. The average ambient temperature between 6 am and 6 pm was 84°F, the average relative humidity was 65%, and the average heat index was 91°F.[16] The data show that agricultural workers experience a high burden of heat-related symptoms including heavy sweating, headaches, dizziness, muscle cramps and nausea, and females had three times the odds of experiencing three or more symptoms compared with male workers.[15] In addition, approximately 80% of participants studied for at least three work days exceeded the internal core body temperature threshold (38°C, or 100.4°F) recommended by the American College of Governmental Industrial Hygienists[34] at least once during a three-day study period.[35] Core body temperature was measured using real-time internal temperature sensors. Fernery workers spent nearly 4 hours in moderate to vigorous activity while crop workers spent 3 hours and nursery workers spent 2 hours in moderate to vigorous activity per workday.[36] This strong university-community partnership has produced substantial data on the extent of HRI among agricultural workers in the US

Most of the research to date with agricultural worker population exposed to heat has focused on describing the problem. The current *Girasoles* research infrastructure presented an ideal opportunity to build on these findings and to investigate cooling interventions that could improve the physiological response to chronic heat exposure and protect workers from HRI.

Conceptual Framework

The Farmworker Vulnerability to Heat Hazards Framework[37] guided this dissertation study and is illustrated in Figure 1. The framework isolates the environmental heat stress hazard (top block). Each individual response (bottom block) is unique due to three intersecting forms of vulnerability to environmental heat stress (middle block): 1. Workplace exposure includes work intensity and duration. 2. Sensitivity includes age, health, gender, and more. 3. Adaptive capacity includes clothing, hydration, and work hygiene. Any or all of these can exacerbate vulnerability to heat stress and result in physiological disequilibrium. The framework isolates the area for measurable cooling interventions at the individual bodily response to heat stress (bottom block). To help individual workers respond to this heat stress, this study focused on improving workers' adaptive capacity by using cooling interventions while working and examining their physiological response to heat stress in light of them.

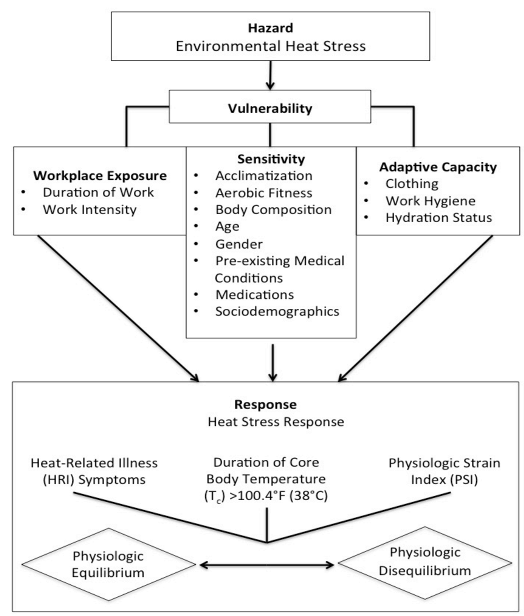


Figure 1. Farmworker vulnerability to heat hazards framework

We hypothesized that individual adaptive capacity can be improved to maintain physiological equilibrium with cooling interventions, and we measured this through indicators of heat stress (core body temperature, self-reported heat-related illness symptoms, and physiological strain index).

Manuscripts Deriving from This Research

Three manuscripts written for publication in peer-reviewed journals are included in this dissertation. Chapter 2 is a systematic review of cooling interventions in outside occupational groups, the feasibility (aim 1) and measurable effects (aim 2) of interventions are addressed in Chapter 3, and qualitative results of worker perceptions and acceptance of cooling devices (aim 1) are presented in Chapter 4.

Summary and Scientific Premise

The scientific premise of this study is supported by our ongoing research, and preliminary data from agricultural workers in Florida[11,17,28,29,37-44] and by other national and international research studies that are documenting the acute and chronic impacts of heat exposure in various agricultural populations. There is limited evidence on cooling interventions for maintaining core body temperature below the recommended physiologic limit, which has led to the development of this dissertation study. To our knowledge, this will be the first US-worksite-based intervention study with agricultural workers randomized to examine multiple cooling gear for the prevention of HRI. The overall goal is to determine which intervention (or combination of interventions) is practical to use while working and the physiological response to using personal cooling gear among agricultural workers. This study uses a mixed methods approach that integrated qualitative and quantitative data to yield a multi-dimensional and synergistic understanding of the results. This study is timely and will set the foundation for identifying evidence-based and culturally-appropriate occupational cooling intervention strategies for keeping workers safer while they labor in extreme heat conditions, reducing HRI and heat-related deaths for agricultural workers in Florida and other regions around the US.

Chapter Two: Systematic Review

Abstract

Background: The purpose of this systematic review is to examine cooling intervention research in outdoor occupations, evaluate the effectiveness of such interventions, and offer recommendations for future studies. This review focuses on outdoor occupational studies conducted at worksites or simulated occupational tasks in climatic chambers.

Methods: This systematic review was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. PubMed, Embase, and Web of Science were searched to identify original research on intervention studies published in peer-reviewed journals that aimed at reducing heat stress or HRI from January 2000 through May 2019.

Results: A systematic search yielded a total of 1014 articles, of which 19 met the inclusion criteria. Occupations with cooling intervention studies included agriculture (n=3), construction (n=5), industrial workers (n=4), and firefighters (n=7). The studies focused on multiple types of cooling interventions: cooling gear (vest, bandanas, cooling shirts, or head-cooling gel pack), modified work anti-stress uniforms, forearm or lower body immersion in cold water, pouring water on head and hands, ingestion of a crushed ice slush drink, electrolyte liquid hydration, and modified OSHA recommendations of drinking water and resting in the shade.

Conclusion: Occupational heat-related illnesses and death may be mitigated by targeted cooling intervention and behavioral and workplace controls among workers of vulnerable occupational groups and industries.

Chapter Two: Cooling Intervention Studies Among Outdoor Occupational Groups: Systematic Review

This chapter provides a comprehensive review of the literature on published studies of cooling interventions designed for outdoor workers conducted at either worksites or in simulated climatic chambers. The occupational groups included in this review are identified as being at increased risk of heat-related illness.

Introduction

Outdoor workers, especially those with physically demanding jobs that expose them to extremely hot temperatures, are identified as occupational groups at increased risk of heat stress and heat-related illness (HRI) associated with climate change.[6] Heat stress is the net heat load a worker is exposed to from combined factors such as metabolic heat, environmental factors, and clothing worn that contribute to increased heat storage in the body. [22] Exposure to a hot environment for a prolonged period while working can result in heat strain that debilitates the body's ability to cool itself, causing HRI and in severe cases heat-related death. HRI is a preventable condition that exists along a continuum from less severe signs and symptoms, such as muscle cramps to heat exhaustion, and heat stroke. [8]

A systematic review, including 111 studies conducted in 30 countries, found that working in hot environments increases the likelihood of experiencing occupational HRI and has negative effects on health and productivity.[45] The risk of heat-related mortality in agricultural workers is 20 times greater than the general workforce population [7] followed by construction workers who are 13 times more at risk of heat-related mortality compared to workers in other industries. [46] While there is much descriptive research on the prevalence and risk of HRI among occupational groups, less work has been published on interventions to decrease the risk of HRI.

The Occupational Safety and Health Administration (OSHA) launched a Heat Illness

Prevention campaign in 2011. The campaign focused on raising awareness about the hazards of working outdoors in hot weather and to encourage workers to take precautions. The primary safety recommendations are to drink water and rest in the shade with a simple message: *Water. Rest. Shade.* OSHA recommends outdoor workers drink eight ounces of water every 20 minutes and drink electrolyte-containing beverages. For rest breaks, OSHA generally recommends resting every hour and taking a long enough rest break for a worker to recover from HRI or prevent HRI. Rest breaks should take place in a shaded area such as under a tent or canopy, or in an air-conditioned automobile or building. While drinking water and resting in the shade along with increased worker knowledge of heat hazards are essential to prevent HRI, heat-related morbidity and mortality rates remain high for vulnerable occupational groups. Additional studies are needed to ascertain the effectiveness of interventions that may augment the beneficial effects of drinking water and resting in the shade.

Systematic reviews of cooling intervention studies have analyzed controlled exercise trials in climatic chambers, typically with athletes running on treadmills, cycling, or other types of aerobic exercises. [47,48] Cooling interventions with athletes have focused on the effects of cooling prior to an exercise test to create a larger heat storage capacity. [47,49] The number of studies of cooling interventions with athletes during an exercise test has recently grown, examining methods such as cooling vests, neck cooling, ingestion of cold fluids or ice slurries, menthol cooling, and water spray cooling. [49] The results of these cooling interventions during exercise trials have been mixed with one meta-analysis [49] reporting that ingesting of cold fluids or ice slurries is the most effective, followed by the use of cooling vests, at improving exercise performance in hot ambient temperature. Another analysis reported unclear effects on biological indicators of heat strain while using cooling interventions during exercise trials. [48] However, studies of athletes are difficult to generalize or apply to outdoor occupational groups with varying physical movements, exertion and environmental conditions. Thus, little is known about cooling interventions in occupational settings, and field studies are needed to validate the effectiveness and practicality of cooling interventions in outdoor occupational groups.

Table 1. Definitions

Term	Definition
Heat stress	The net heat load a worker may be exposed from the combined contributions of metabolic heat, environmental factors, and clothing worn.(NIOSH, 2016)
Heat strain	The overall physiological response resulting from heat stress.(NIOSH, 2016)
Heat-related illnesses (HRI)	Conditions that exist along a continuum from less severe illnesses, such as muscle cramps to heat exhaustion, and heat stroke.(Atha, 2013)
Physiological strain index (PSI)	An index that evaluates heat strain based on physiological parameters of heart rate and rectal temperature, that depicts the combined strain reflected by the cardiovascular and thermoregulatory systems. The index ranges from 0–10, where "0" presents no strain and "10" very strenuous physiological conditions.(Moran, Shitzer, & Pandolf, 1998)
Perceptual strain index (PeSI)	Measures the thermal strain in individuals through the thermal sensation (TS) and the Rating of Perceived Exertion (RPE).(Tikuisis, McLellan, & Selkirk, 2002)
Rated perceived exertion (RPE)	A scale that measures the perceived intensity of physical exertion.(Borg, 1990)
Thermal sensation (TS)	Perceived temperature sensation related to skin and ambient air temperature.(Gagge, Stolwijk, & Saltin, 1969)

The purpose of this paper is to review previous cooling intervention research in outdoor occupations, evaluate the effectiveness of such interventions, and offer recommendations for future studies. This comprehensive review of the literature focuses on outdoor occupational studies conducted at worksites or simulated occupational tasks in climatic chambers.

Methods

This systematic review was performed in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines.[50] PubMed, Embase, and Web of Science were searched to identify original research on intervention studies published in peer-reviewed journals that aimed at reducing heat stress or HRI. Search terms included a combination of words and closely related words: 'heat stress', heat strain', 'heat stroke', 'heat-related illness', 'body temperature changes', 'occupational, outdoors', 'manual labor', 'cooling intervention', 'cooling intervention', and 'heat intervention.' (See Table 1.)

The search was limited to studies published in the English language from January 2000 through May 2019. Studies with adult humans participating in cooling interventions at occupational worksites outdoors or simulated occupational tasks in climatic chambers were included. The focus was on outdoor environmental and occupational heat exposure and cooling interventions to prevent HRI. Outcomes of focus were dehydration, body temperature, heart rate (HR), physiological strain index (PSI), HRI symptoms, and subjective measures. Dehydration, body temperature, HR, and PSI are physiological indicators of heat strain on the human body. We excluded animal studies, indoor heat exposure or exercise trials in climatic chambers. Studies with indoor occupations or exercise trials in climatic chambers were excluded as these are difficult to generalize to outside occupational groups with different environmental heat exposures, and physical movements during exercise trials varies from physical movement at work. Case reports, editorial letters, case series studies, and intervention studies without a comparison group were al so excluded.

All titles and abstracts from the literature search were evaluated according to the above inclusion criteria. Relevant articles were included, and the full-text articles were evaluated using the same inclusion and exclusion criteria. The study selection process is illustrated in Figure 1.

Results

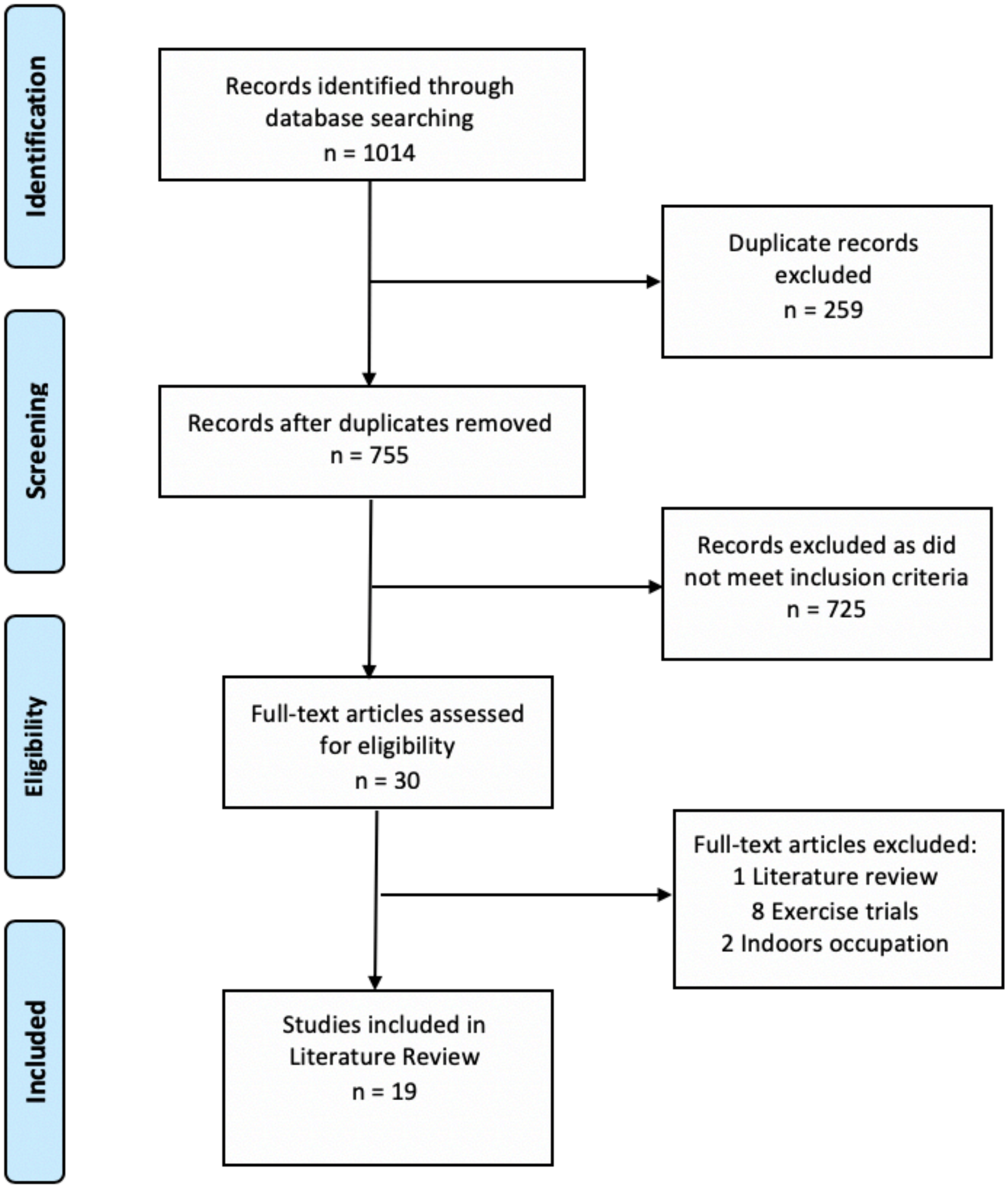
A systematic search of PubMed, Embase, and Web of Science yielded a total of 1014 articles published from 2000 – May 2019. There were 259 duplicate articles removed. After removing duplicates, 755 articles were eligible for preliminary title and abstract screening. After screening titles and abstracts, 30 full text articles were reviewed and 11 were removed for not meeting inclusion criteria. A total of 19 peer-reviewed papers met the inclusion criteria and were selected to be part of this review. A summary of the PRISMA protocol and reasons for excluding articles are shown in Figure 1.

Studies with a variety of cooling interventions, protocols used, and health outcomes were included in the review. Most studies were conducted in the USA (n=6, 32%) followed by China (n=4,21%), and India (n=2,11%). One study in El Salvador resulted in two publications, one examining the outcomes of dehydration, HRI symptoms and productivity, while the second paper examined *estimated glomerular filtration rate* (eGFR).[20,51] The United Kingdom, Korea, Brazil, Iran, and Australia each had one published cooling intervention study. Randomization assignment of intervention was used in 15 (79%) studies and 4 (21%) studies were quasi-experimental design studies.

Occupations with cooling intervention studies included agriculture (n=3), construction (n=5), industrial workers (n=4), and firefighters (n=7). Only four studies enrolled female workers, though with a small proportion of females compared to mostly male workers. The studies focused on multiple types of cooling interventions: cooling gear (vest, bandanas, cooling shirts, or head cooling gel pack), modified work anti-stress uniforms, forearm or lower body immersion in cold water, pouring water on head and hands, ingestion of a crushed ice slush drink, electrolyte liquid hydration, and modified OSHA recommendations of drinking water and resting in the shade.

Biological indicators of heat stress such as body temperature, HR, and PSI were measured, though only three studies measured all three indicators [52-54]. Two studies did not record objective measures of body temperature, HR, or PSI [20,51,55,56]. The remaining studies had a combination of objective and/or subjective measures of heat stress. Body temperature was assessed via oral, rectal, or tympanic thermometers, or ingestible sensor pills. HR was measured primarily with a chest strap monitor.

Figure 1. PRISMA Flow Diagram



All firefighter cooling intervention studies (n=7) were done during simulated fire-drills on field training sites, which is part of normal training for firefighters. Participants in firefighter studies wore their full personal protective equipment and self-contained breathing apparatus. Of the remaining occupational sector jobs, nine of the twelve studies were conducted at the worksite, while three were conducted in a climatic chamber simulating work activity.

The longest trials were conducted by Bodin et al. (2016) and Wegman et al. (2018) over an agricultural harvest period. In contrast, four of the 16 studies at worksites examined cooling interventions on one to four workdays. Among the agricultural, construction, and industrial cooling interventions studies, five of the trials were 2 hours or less [21,53,57-59]. Due to the nature of the extreme heat exposure (82°C - 309°C) firefighters encounter, those trials were less than 2 hours.

The majority of the cooling intervention studies included a modified OSHA work-to-rest ratio protocol that was adhered to both in climatic chambers and at worksites. Firefighter studies all included a recovery period at the end of the fire drills. The time range of the fire drills ranged from 12 to 88 minutes with heat exposure ranging from 82°C to 309°C. The recovery period in three (60%) of the studies was 15 minutes, while a study in the United Kingdom had a recovery period of 20 minutes, and another study in the USA had 30 minutes of recovery. The minimum industry standard is a 10-minute recovery period.[60]

Water, Rest, Shade

In El Salvador, a longitudinal study over a harvest period implemented modified recommendations from OSHA's Water, Rest, Shade guidelines [20,51]. This is the only field study conducted with agricultural workers that examined the impact of interventions on symptoms of HRI and renal function [20,51]. Originally the investigators planned on implementing the OHSA recommendations with two groups of workers in coastal low-lands where ambient temperatures and humidity are high and inland workers who are exposed to less severe climatic conditions. Due to security concerns the investigators were unable to test the intervention in the coastal group. Agricultural workers (n= 41) in the inland area began the interventions two months into a five-month harvest by wearing 3-liter backpacks with water to drink from while working, They were instructed to rest 15 minutes every hour in a shaded canopy that was moved through the field, and they used an ergonomic machete for cutting sugarcane.

While a strength of the study was a longitudinal intervention effectiveness design, there was no inland area control group, nor a comparison group in the coastal area. However, workers reported less HRI symptoms and increased self-reported water consumption at post-intervention compared to pre-intervention [20]. Wegman et al., (2018) reported on the effect of the intervention on biomarkers of dehydration and kidney damage. At the end of the harvest, the intervention group showed a decline in eGFR -3.4 mL/min/1.73m^2 compared to pre-intervention levels (95% CI -5.5, -1.3). The investigators compared this drop in renal function to the group of workers in the coastal area who did not have the intervention and reported a greater decline in eGFR -5.3 mL/min/1.73m^2 (95% CI -7.9, -2.7) over the harvest period [51]. The authors concluded that the intervention applied only in the inland worker group lessened the decrease in eGFR during a harvest period.

Although dehydration is identified as a possible risk factor for the development of Mesoamerican nephropathy, and urine samples were collected pre-shift and post-shift on three different visits during the harvest, no objective measures of hydration, such as urine specific gravity were reported. Instead symptoms of “dry mouth” and the self-report of “very little urine” were used as proxy measures of dehydration [20]. While these reports provide insight on the potential for rest-water-shade interventions to decrease HRI symptoms, and indicators of renal dysfunction, the validity of comparing pre- and post-harvest measures in workers from two different climatic regions of which only one region received the intervention is a serious limitation in the study design.

However, the ability to assess the effect of an intervention over a harvest period albeit in only one group is a strength.

Anti-heat stress clothing

Two reports described results of a study of the effectiveness of an anti-heat stress shirt and work pants uniform that used fabric with thermal-moisture properties and loose-fitting design for Chinese construction workers [55,56]. Chan et al. (2016) described the acceptability of a loose-fitting anti-heat stress collar shirt made of 100% polyester light blue fabric with moisture-wicking technology (COOLMAX® by Invista, Wichita, Kansas). The moisture-wicking fabric pulls moisture away from the skin to the outer surface of the fabric, which makes it easier to evaporate and doesn't saturate the fabric. The pants were a khaki color made of 40% polyester and 60% cotton. Positive subjective perception of performance was reported by 184 construction workers (7 were females) and resulted in 35% performance improvement [55].

In a later study, construction workers (n=16) were randomized to either the anti-heat stress uniform or usual work uniform group in a counter-balance order in the morning and afternoon on one work day [56]. The anti-heat stress shirt was made of 65% cotton, 35% polyester with thermal-moisture properties, porous reflective strips, and meshed fabric on the sides. Pants were 100% cotton and loose-fitting. Participants worked for 135 minutes in the morning and afternoon. Participants rested for 30 minutes in an air-conditioned room (22°C) prior to the start of the workday, had lunch in an air-conditioned room, and recovered for 30 minutes at the end of the trial in an air-conditioned room. Participants wore a monitor that captured heart rate (HR) every minute. Rated perceived exertion (RPE) and thermal sensation (TS) was reported by participants every 5 minutes which would not be practical protocol in most occupational settings. It is also reasonable to infer that stopping every 5 minutes to report RPE and TS can contribute to lower heat strain and does not reflect the actual work routine of workers. There was no difference observed in HR and

RPE between groups. The perceptual strain index (PeSI) was calculated from TS and RPE. TS was assessed with a scale ranging from 1 (cold) to 7 (hot) every 5 minutes. Yang et al. (2017) reported that perceptual strain index (PeSI) was statistically lower in the intervention group (4.47 ± 1.85) compared to the control group (4.78 ± 1.82, $p < 0.05$). However, the mean PeSI for both groups was still within the same category of "low heat strain" [61].

Gel and Phase Change Material Cooling gear

In Korea, 12 agricultural workers were randomized to multiple cooling gear that included bandanas, hat, vest, combination groups, and a control group [21]. The agricultural workers simulated red pepper harvest picking in a climatic chamber (WBGT33°C) for 120 minutes (two bouts of 50-minutes work with a 10-minute rest) and the interval between successive experiments was a minimum of three days. Rectal temperature was measured with a thermometer every minute by remaining inserted at the depth of about 13 cm in the rectum during each experiment. Eight intervention groups consisted of: 1) the control group used long cotton shirts and cotton pants as agricultural workers usually wear; 2) another group used a neck bandana with 60 oz. of frozen gel; 3) one used a neck bandana with 180 oz. of frozen gel; 4) one used a hat made of reflective fabric with a pocket around the neck to insert a 180 oz. frozen gel pack; 5) one used a vest with pockets for inserting four-180 oz. gel packs; 6) one combined the hat used in group 4 and the bandana used in group 3; 7) one combined the hat used in group 4 and the vest used in group 5; 8) one combined the hat used in group 4, the vest from group 5, and the bandana from group 3. The three combination groups (groups 6-8) had greater body surface areas exposed to cooling gear and had no participants with rectal temperatures of ≥38°C ($p<0.05$). Eight out of 12 participants in the group without a cooling intervention spent an average time of 37 minutes with a rectal temperature at ≥38°C. The average time spent at ≥38°C ranged from 2-18 minutes in the groups with a single cooling item. No difference in HR was reported among the eight groups. Over 80% of the participants in each intervention group reported the cooling gear was "comfortable" or "a little uncomfortable." Limitations of this study are the small sample size and that a 120-minute trial is not reflective of an entire work shift.

Two cooling intervention studies with construction workers assessed the effectiveness of cooling vests in China (WBGT range 29°C-33°C) [52,62]. The vests had built in fans and phase change material (PCM) inserts that were tested at worksites where WBGT ranged from 29°C-31°C [52,62]. PCM melts at a lower temperature therefore maintaining its cooling effect longer. Important to note is that the vest was only worn during the workers' scheduled rest breaks. Additionally, participants in both studies wore anti-heat stress work uniforms with thermal-moisture properties (the same uniform in the intervention study by Chan et al. 2016 discussed above).

A construction field study with 140 workers examined PCM vest over a two-day trial [62]. On one day, participants wore a PCM vest during two rest breaks —15 minutes in the morning and 30 minutes in the afternoon — and the second day no PCM vest was worn during the two rest breaks. Method of allocating participants to the groups (intervention and control) on the two-day trial were not reported. Heart rate was monitored with a belt around their chest. Paired-sample t-test showed significant difference in the average drop per minute of HR while resting while wearing the vest as compared to the control group (4.79 ± 6.55, 10.43 ± 6.63, $p < 0.001$). Participants reported their ratings for measurements of perceptual heat strain index (PeSI), thermal sensations (TS), and rate of perceived exertion (RPE). TS and RPE were improved in the intervention group but was not significant. PeSI scores improved in both groups after 15-minute rest break and improved even more after the 30-minute rest break. However, PeSI scores improved significantly in the intervention group ($p < 0.001$). The interaction of time and using anti-heat stress work uniforms showed a significant influence on the alleviation of PeSI [62].

In another study in China, 14 construction workers participated in two-day consecutive trial where they were allocated to either the control group or the PCM vest intervention group in a counter-balanced order [52]. The protocol for this study included a mandatory 15-minute break in the morning, one-hour lunch, and a 30-minute break in the afternoon during a 7-hour work shift. Participants were encouraged to drink water to rehydrate in a structured manner by placing fluids near the work site. Core temperature was estimated with tympanic temperature measured every 5 minutes. HR was monitored at 1-second intervals with a monitor around their chest. RPE was taken every 5-minutes using the Borg CR-10 scale. TS was assessed with a scale ranging from 1 (cold) to 7 (hot) every 5 minutes. The protocol of measuring TS, RPE, and tympanic temperature provides an additional respite time from heat stress that most workers in occupational settings do not have. PSI and PeSI was also measured. The intervention group wearing PCM vests had lower estimated core temperatures ($F = 17.95$, $p<0.01$), HR ($F = 16.01$, $p<0.01$), and PSI (1.03 ± 0.53, $p = 0.02$) when compared to the control group not wearing the PCM vest [52]. However, core temperature was estimated by tympanic temperature and should be interpreted with caution. External measuring devices have been reported to fail at accurately predicting core body temperature after exertion [63]. HR was significantly lower in the cooling group ($F = 9.75$, $p = 0.04$; $F=16.01$, $p<0.01$), as was PSI, PeSI, RPE, and TS compared to the control group. Although PSI was reported to be significantly lower in the intervention group, both groups had a PSI range of 1 to 2 which is categorized as little to low strain. The 14 participants had a mean age of 29 ± 3.32 and normal weight (BMI was 21.2 ± 2.17). Interestingly, the site managers were responsible for ensuring PCM remained cold in an insulated box.

In a simulated, intervention study, PCM inserts were placed in the pockets of compression undergarments in 20 college-aged, non-smoking, healthy males [53]. It is unclear if the participants were actual industrial workers since there is no mention of them being industrial workers and were instead described as college-aged males. Simulated industrial tasks were conducted in a climatic chamber at WBGT 34°C for 85 minutes, which included OSHA work-to-rest ratios recommendations. They were tasked with carrying boxes, loosening and tightening nuts and bolts, and walking over steps while carrying weights. Participants were required to have USG less than 1.025 before starting the trial. The intervention group had lower mean rectal temperature and PSI than the control group ($p < 0.05$). Performance was measured based on the amount of work cycles completed. No difference in performance was noted in both groups.

A study with 10 firefighters (male n=6, female n=4) with a randomized two group design was used to examine the effect of a cooling vest during simulated fire and rescue activities in 170°C firehouse [64]. The trials ranged from 34-39 minutes. Core body temperature was recorded in 20-second intervals with an ingestible temperature sensor. HR was monitored every five seconds with a chest strap monitor. RPE and TS were obtained pre and post-trial. The PCM cooling vest had no significant effect on HR or core temperature, RPE, or TS [64]. In Iran, 15 firefighters participated in four 45-minute simulated firefighting activities in a smoke-diving room at 28-30°C with a RH 55%-60% [65]. All participants were randomized to 1) control (no cooling device); 2) cooling gel containing menthol; 3) PCM cooling vest; and 4) combination of both the cooling gel with menthol and PCM cooling vest to use during the trials. Menthol cooling gel was applied to the forehead and neck. HR was measured in one-minute intervals with a chest strap monitor. Temporal artery temperature was measured pre and post each trial. HR and temporal temperature were significantly lower in the PCM vest group at the end of the trials ($P < 0.05$) [65]. An important consideration is that temporal artery temperature has been shown to be inaccurate measure of core temperature under heat stress conditions [66].

Recirculated liquid ice-chilled coolant vest

In India, construction workers (n=29) used a vest that recirculated liquid ice-chilled coolant through silicone rubber tubing via a small battery-operated motor pump for 90-minutes followed by 30-minute rest and then 90-minutes without the vest (control) [57]. The chilled water circulated the participant' chest area to absorb excess heat from the participant's body. The HR was significantly lower at the end of the trial of wearing the cooling vest compared to at the end of the trial without wearing the cooling vest ($p < .05$) [57]. The protocol included a work–rest cycle of 75% work and 25% rest each hour and stopped participants from working every 15-minutes to obtain oral temperature [57]. HR was lower in cooling vest group compared to the control group at the end of the trial, (106 ± 13, 117 ± 12, $p < .05$, respectively). No difference was observed in oral temperature at the end of the trial. Participants reported the cooling vest kept them comfortable and cool. The control grouped reported feeling uncomfortable and hot. This was the only study to report the cost ($50) of the vest.

A study with 24 foundry workers in India similarly to Ashtekar et al. (2019) examined a vest that also recirculated liquid ice-chilled coolant through silicone rubber tubing via a small battery-operated motor pump for 90-minutes followed and then 90-minutes without the vest (control) [58]. The protocol included a work–rest cycle of 75% work and 25% rest each hour. Similar to the study in India with construction workers, this study also measured oral temperature every 15-minutes and monitored HR with a chest strap monitor. No difference was observed over a 90-minute trials in oral temperature or HR between cooling vest group and control group. Participants in the intervention group reported a mean score of 4.5 out of 5 points in perceived comfort, efficacy and efficiency indicating workers could perform their routine work without disturbance.

Another study examined a shirt that recirculated ~15 liters of liquid ice-chilled coolant via a small battery-operated motor pump with 12 male graduate students who simulated 30 minutes of power utility tasks outdoors in WBGT ranging from 32°C – 38°C [59]. Simulated tasks included installing insulators with bolts, washers, and nuts and uninstalling, cutting wires, and constructing a double tie using aluminum conductors steel reinforced. HR was monitored with a chest strap monitor and was not statistically different between the group with the cooling shirt and the group without it. Tympanic temperature was significantly lower with the cooling shirt ($p = .003$) although the mean tympanic temperature for the outdoor group not using the cooling suit was 37.4°C which is under the 38°C recommended limit. Higher productivity was reported while using the cooling shirt compared to not using the cooling shirt outdoors ($p = .011$).

Twenty-five firefighters completed a simulated fire suppression and then 30 minutes of recovery time [67]. At the start of recovery time, participants were randomized into one of three groups: 1) liquid perfused cooling vest; 2) forearm immersion in cold water (20°C); or 3) passive cooling in an air condition medical trailer at 22.2 ± 0.6°C. The participants in the cooling vest group and forearm immersion group recovered outdoors in the shade in 22.5 ± 2.9°C, RH 47.2 ± 11.0%. Core temperature was measured with an ingestible temperature sensor and HR with a chest monitor strap every five minute during the recovery period. Cooling rates ($°C \cdot min^{-1}$) among the groups were significantly different with the forearm water immersion group with a cooling rate of 0.05±0.04, followed by the cooling vest group at 0.03±0.04, and the passive cooling group had a cooling rate of 0.03±0.02. However, survival analysis of the cooling interventions did not differ in HR and core temperature during the 30-minute recovery period [67]. The majority of participants did not reach the set criteria of HR <80 bpm at the 30-minute rest interval for full recovery from heat stress exposure.

Cold water immersion

After a 12-minute live fire drill (190 to 309°C), 50 firefighters were randomized to either standard rehabilitation procedure of resting in the shade (33°C, RH 33%) and drinking cool beverages ad libitum for 15-minutes or to the intervention group that included standard rehabilitation procedure and forearm immersion in 10°C water [68]. Core temperature was monitored with an ingestible pill sensor and HR with a chest strap monitor. Mean core temperature at the end of rehabilitation period was 38.5°C for control and 38.2°C for intervention group (p-value < 0.001). Forearm immersion resulted in a 0.28 °C (95% CI 0.06-0.50) decrease in core temperature and a 19.4 bpm (95% CI 12.0–26.8) decrease in mean HR at the end of rehabilitation period [68].

Twenty-seven firefighters were randomized into one of three groups: 1) one wearing cold gel pack in helmet during live-fire drill, 2) another with forearm water (5°C) immersion for 15 minutes during the rehabilitation period, and 3) the control group without active cooling [54]. All participants completed two sets of two 15-minute drills followed by a 15-minute recovery period outside in the shade. Recovery period began when all participants were seated in the recovery area. No difference was observed in HR, core temperature, or PSI in the cold gel helmet group. Core body temperature was monitored with an ingestible pill sensor and HR was measured with a chest strap monitor. Mean core temperature was significantly lower at the end of the rehabilitation period in the forearm cold water immersion group (37.68°C ±0.28) compared to head cooling group (38.62°C ±0.28) and control group (38.36°C ±0.46). PSI was significantly reduced in the forearm immersion group compared to the other two groups, but HR was not different among the three groups.

In another multi-intervention study, firefighters conducted two 20-minute simulated search and rescue drills in 105°C chamber with furniture configured as in a typical house [69]. Participants were randomly allocated to one of three groups for the 15-minute recovery period: 1) one immersing the lower body up to the umbilicus level in 15°C water (upper limbs were not immersed in water) pool with a portable chilling unit outside in the shade at 19.3 °C; 2) another consuming a crushed ice (–1°C) slush drink at 7 $g \cdot kg^{-1}$ of body weight; and 3) one sitting in the shade after removing their boots and specialized personal protective clothing. Core temperatures were monitored via an ingestible pill sensor and the Borg scale for RPE. Core temperature and cooling rate was significantly lower at the end of the 15-minute cooling period in both interventions as compared to the control group. However, no difference was observed between lower body immersion in cold water and consuming crushed ice slush drink. No difference was detected in RPE among the three groups.

Nutritional intervention

Twenty-one firefighters participated in a counterbalance randomized trial that examined an enhanced cooling nutritional intervention [70]. Participants performed two 18-minute fire drills (71–82°C) separated by 48 hours between the two drills. After the drill, all participants recovered in a 20°C room and were allocated to the control group or the enhanced cooling nutritional group. The intervention group required participants to drink up to 355 milliliter (ml) of a recovery drink with 20 grams of carbohydrate and five grams of protein within the first 10-minutes of recovery. In addition, the intervention group also could drink up to 500ml of water and at least 355ml of a sport drink and used cold towels. The authors did not report if the fluids consumed were cold or room temperature, nor did they report where on the body the cold towels were placed. An ingestible pill sensor was used to monitor core temperature and a chest strap to monitor HR. It was not reported at what interval the core temperature and HR were monitored at. There was no difference observed in HR or core temperature.

Water poured on head and hands

In Brazil, eight steel workers exposed to WBGT of 26°C - 29°C at the worksite poured two liters of water at 23.5°C on their head and hands over one-minute ten times during the work shift [71]. The steel workers participated in a four-day trial and divided into two groups with participants in each group. Participants were randomized to one of the two groups. The first group participated in the control (usual work practices) for two consecutive days followed by two days of pouring water on their hands and head at schedule times. The second group followed the same protocol but in inverse order. No differences were reported in tympanic temperature or HR. The intervention group had lower report of tiredness, which was measured with an analogue scale that ranged from "much better" to "same" to "much worse" ($p < 0.05$). Although HRI symptoms were assessed during the trials, the authors reported that during the intervention days only one complain of limb fatigue was reported but there was no mention if this was statistically significant. There was no report of the number of HRI symptoms reported on the control days.

Discussion

Cooling intervention studies with vulnerable occupational groups has become of interest to researchers as rates of heat-related morbidity and mortality are high and expected to get worse with rising global temperatures [6]. The results of heat-related morbidity and mortality include loss of labor productivity for companies but also loss of income for occupational groups that already have low wages [45]. Seventeen of the 19 studies in this review included administrative controls to reduce the impact of heat stress in addition to cooling gear. Administrative controls are aimed at reducing the exposure to hazardous conditions, which in this case is heat. Work practices or policies such as work-rest cycles, provisions of water, and ensuring workers drink adequate amounts of water are just three examples of administrative controls [22]. However, heat stress prevention standards from government bodies across the globe are lacking, and even where standards do exist enforcement is minimal as HRI rates remain high [72,73]. Some countries have launched heat prevention educational campaigns and have made strong recommendations for employers to protect workers from heat stress, but recommendations are not easily enforceable.

PCM cooling studies included in this review were shown to be effective cooling interventions at mitigating occupational heat stress [52,53,62,65]. Two of the studies successfully examined PCM vests during full workdays with construction workers suggesting PCM vests have the potential to be implemented in other outdoor occupational sectors, such as in agriculture or industrial sectors.

However, it is important to note that the PCM vests were used on top of anti-heat stress work uniforms, while resting for 15-minutes in the morning and 30 minutes in the afternoon resulted in significant improvement of HR, temperature, PSI, and/or worker comfort [52,55,62].

Cooling vests work by conductive cooling when heat flows from an object that is hot to an object in physical contact that is cooler, to create thermal equilibrium. The cooling vest and anti-heat stress work uniforms performed well in surveys measuring subjective responses of work performance and usability. Specifically, Zhao et al.'s (2018) study with 14 construction workers showed improvements in estimated core temperature, HR, and PSI as well as significant improvement in subjective measures of perceived cooling and thermal sensation. It is important to highlight that this study had administrative controls in place that encouraged workers to drink water by placing water near workers and the site manager ensured the PCM inserts remained cold in an insulated box for use by workers during the two scheduled rest breaks. That is, work practices instituted by employers also affect the work conditions of the employees.

Zhao et al.'s (2018) study shows how a combination of administrative controls, personal cooling gear, and the participation of worksite managers can work in synergy to reduce occupational heat stress and protect workers. Although this is a field-based study, the construction industry in China adheres to a heat stress policy to protect workers unlike the majority of outdoor jobs where neither industry nor government regulations implement structured mandatory rest breaks, and work heat thresholds are not used to monitor safe working conditions. In 2012, China implemented administrative measures for an occupational heat stress policy to protect workers from heat stress at the national level [74]. This policy is a threshold system that stops all work outdoors once temperature reaches ≥40°C, at ≥37°C to <40°C work is limited to ≤6 hours a day, and when the maximum temperature is ≥35°C to <37°C outside workers receive a high-temperature allowance [74]. Nonetheless, there are no reports on the impact these regulations have had themselves.

The longitudinal study in El Salvador examined workers over a harvest (~5 months), and showed smaller reduction in eGFR, improved work performance, and a reduction in HRI symptoms with an OSHA modified water, rest, shade intervention [20,51]. Initially, resting in the shade every hour was met with skepticism by the workers in El Salvador [20]. Taking 15-minute breaks every hour during high temperature may be perceived as a barrier to work efficiency and production. Nonetheless, in El Salvador, the individual daily average production increased along with improved work satisfaction suggesting that harsh working conditions can be modified to protect agricultural workers without negatively impacting production [20]. El Salvador does not have heat stress prevention standards. However, the sugar mill where the studies were carried out funded the interventions.

Forearm water immersion for 15 minutes was shown to be better at decreasing core body temperature and HR after fire drills compared to the other interventions examined [54,67-69]. Forearm immersion in cold water decreases core temperature by exchanging heat between superficial blood vessels in the extremity and the water. While this protocol may be appropriate for the firefighter industry, it may be challenging to implement in the agricultural, construction, and industrial sectors unless the employer implemented a work practice to have a collapsible chair with water-immersion arm holders and large amounts of cold (<20°) water readily available. Many fire agencies follow the National Firefighter Protection Association (NFPA) standard 1584, which requires a structured rehabilitation period, rehydration, and monitoring by a member of the fire department; however, the guidelines for cooling are not specific [60]. Nonetheless, the adoption by fire agencies of NFPA standard 1584 is a commitment by the fire agency to protect its workforce and mitigate the negative health effects of occupational heat stress.

Among the agricultural, construction, and industrial worker cooling interventions studies, 41% of the trials were 2 hours or less [21,53,57-59]. Working in direct sunlight and performing >2 hours of prolonged or strenuous work increases the risk of HRI. Agricultural, construction and industrial workers have strenuous jobs and work long hours in direct sunlight. Future protocols should have minimal interference in work routine by not stopping workers every 5 or 15 minutes to obtain measures. Thus, it is important to assess the all-day work use of cooling interventions in order to determine efficacy and usability of the cooling gear. Even though some cooling interventions have shown a reduction in HRI, improved body temperature and HR, the sample size of several of the studies were small and of short work duration. Therefore, the successful implementation of cooling interventions in large occupational groups with diverse characteristics and work hours and routines remains uncertain and future research should be conducted at a large scale.

Implementation of work-rest cycles at worksites is a barrier in light of the unwillingness of sectors to incorporate them due to the perception of potential loss in production and revenue and lack of heat prevention standards. Many of the studies included work-rest cycles without significant decrease in performance or production losses. Cooling gear has the capacity to protect workers from HRI and to augment the protectiveness of water, rest, and shade [21,52,62].

The use of work-rest schedules in conjunction with a combination of cooling such as the use of a cooling vest and bandana or cooling vest and anti-heat stress work uniform requires further study. Only one study reported the cost of the vest as $50 [57] while none of the other studies reported the cost of the cooling devices. Future cooling intervention studies should report the costs of cooling gear. Future studies should include economic evaluation measuring productivity and a cost-benefit analysis to determine if investment in cooling gear benefits outweigh the cost of implementing such interventions.

More female participants are needed in occupational cooling studies in light of changing demographics of the outdoor occupational sectors that have led to increased workforce diversity [75,76]. In addition, there are sex-related differences in heat stress tolerance and previous results have showed females report three or more symptoms more frequently than males (OR=2.67, 95%CI: 1.1, 6.6) [15]. Therefore, examining for differences in effect of cooling gear at reducing the occurrence of symptoms of HRI and heat strain is needed. Female anthropometrics must be regarded in cooling interventions where properly fitting personal protective equipment is necessary to safeguard efficacy and usability. Studies with females are needed as they represent a significant portion of outside workers and also have high rates of HRI [15,77,78].

Conclusion

Global climate change has resulted in record setting higher temperatures and an increase in frequency of hot days. It is expected there will be a rise in occupational heat-related illnesses and injuries and death along with productivity losses. However, the impact may be mitigated by adaptation to heat through targeted interventions in behavioral and workplace controls among workers of vulnerable occupational groups and industries. Heat-related illnesses and death are preventable. Cooling research studies for an often overlooked, but important, vulnerable group of workers must be treated as a research priority in occupational and public health.

Table 1. Characteristics of cooling intervention studies of outside occupational groups (n=19)

Authors (Year)	Methods	Intervention	T_c	HR	PSI or PeSI	Hydration/ Renal	HRI symptoms	Subjective evaluations
Water, Rest, Shade								
Bodin et al. (2016)[1]	n=60 Worksites over harvest period	Non-randomized H_20 (3L backpack) Rest (15 mins/hr) Shade (canopy) n=60 Worksites over harvest period	NR	NR	NR	NR	Decrease symptoms reported in coastland intervention group	Workers reported positive comments about resting in the shade
Wegman et al. (2018)[2]	n=80 Worksites over harvest period	Non-randomized H_20 (3L backpack) Rest (15 mins/hr) Shade (canopy)	NR	NR	NR	Smaller decrease in eGFR: -3.4 mL/min/1.73m^2 (95% CI -5.5 to -1.3)	NR	NR
Anti-heat Stress Uniform								
Chan et al. (2016)[3]	n=184 Worksite 2 workdays Control/ Intervention	Randomized Anti-heat stress work uniform: Coolmax collar shirt in light blue and Nano-tex Dry-Inside fabric in khaki color	NR	NR	NR	NR	NR	Improved work performance by over 35%
Yang et al. (2017)[4]	n=16 Worksite 135-minute of wear trial	Randomized Anti-heat stress work uniform: Shirt (65% cotton, 35% polyester) and pants (100% cotton).	NR	No difference	PeSI 4.47 ± 1.85 for Intervention vs. 4.78 ± 1.82 for Control, ($p < 0.05$)	NR	NR	Improved comfort and less work performance interference
Cooling Devices								
Ashtekar et al. (2019)[5]	n=29 Worksites 210 min = 90-min intervention, 30-	Non-randomized Vest - liquid ice-chilled coolant recirculated via a small battery-operated motor pump.	No difference	HR 89.7 ± 34.3 ($p < .05$)	NR	NR	NR	cooling vest kept them comfortable and cool

	min rest, 90-min control							
Butts et al. (2017)[6]	n=20 Industrial simulated work in climatic chamber 85 min (30 min spent resting)	Randomized counter-balanced Compression clothing with PCM inserts	Intervention group lower rectal temperature (p<0.05)	HR lower in intervention group (p<0.05)	PSI lower in intervention group (p < 0.05)	NR	NR	Rate of perceived exertion lower with PCM (p<0.05)
,Chan et al. (2017)[7]	n=140 Worksites Vest worn at 15-min break in the AM and 30-min break in the PM	No report of randomization Hybrid cooling vest with phase change materials (PCM) with ventilation fans	NR	HR mean 5.64 ± 7.83 (p <0.001) BPM lower	PeSI scores improved group (p < 0.001)	NR	NR	91% preferred PCM cooling vest as method for cooling during rest time
Furtado et al. (2007)[8]	n=12 Simulated work outdoors - three - 30 min trials	Randomized Cooling suit - liquid ice-chilled coolant recirculated via a small battery-operated motor pump.	Tympanic temperature lower (p = .003).	No difference	NR	NR	NR	Higher productivity with cooling suit vs. no cooling suit (p = .011)
Shirish et al. (2016)[9]	n=24 Work site 90-min intervention and 90-min control 75% work–25% rest each hour	Non-randomized Vest - liquid ice-chilled coolant recirculated via a small battery-operated motor pump.	No difference	No difference	NR	NR	NR	Mean score of 4.5 out of 5 points in comfort, efficacy and efficiency
Zhao et al. (2018)[10]	n=14 Worksite Vest worn at 15-min break in the AM and 30-min break in the PM	Randomized counter-balance order cooling vest with phase change materials (PCM) with ventilation fans	lower estimated core temperature (*F* = 17.95, p<0.01)	HR lower (*F* = 16.01, p<0.01),	PSI statistically lower	NR	NR	Thermal comfort was significantly better p < 0.05
Water Immersion								
Burgess et al. (2012)[11]	n=50 Live-fire drill	Randomized	Rate of core temperature decrease	Rate of HR decrease by 19.4 (95%	NR	NR	NR	NR

	12 min	Post-fire forearm immersion in 10°C water for 15 min in 32.5°C ambient temperature.	0.28 °C (95% CI 0.06-0.50)	CI 12.0–26.8) BPM				
Nutritional Cooling								
Horn et al. (2011)[12]	n=23 Live-fire drill 18 min	Randomized Consumed 500 mL of water, 355 mL sport drink, 355 mL of recovery drink, and applied cold towels during 15-minute rehabilitation period	No difference	No difference	NR	NR	NR	NR
Water Poured on Head and Hands								
Fujii et al. (2007)[13]	n=8 Worksite of steel workers 4 days = 2 days intervention, 2 days control	Randomized 2 liters of water at 23.5°C, poured on the head and hands every hour	No difference	No difference	NR	NR	One report of limb fatigue during intervention days	Tiredness statistically lower in the intervention group ($p < 0.05$).
Multiple Cooling								
Carter et al. (2007)[14]	n=10 3 trials of simulated fire and rescue activities 20-88 min	Randomized During simulation PCM cooling vest worn. Post-simulation forearms immersed in cold water (10°C) for 20 min.	No difference	No difference	NR	NR	NR	No difference in RPE or TS
Choi et al. (2008)[15]	n=12 Simulated agricultural work in climatic chamber 120 min = two bouts of 50-min harvest work with a 10- min rest	Randomized 1. Control 2. Scarf A 3. Scarf B 4. Hat 5. Vest 6. Hat + Scarf B 7. Hat + Vest 8. Hat + Scarf B + Vest	Combination groups did not have rectal temperatures ≥38°C Group 4, 5, 6 7,8 had significantly lower rectal temperature than groups 1,2,3	No difference	Heat storage was significant better in the intervention groups than the control group	NR	NR	80% reported all cooling gear was “comfortable or “a little uncomfortable

Colburn et al. (2011)[16]	n=25 Live-fire drill 20 min	Randomized 30-minute recovery period using a cooling vest, forearm immersion in water (20°C), or passive cooling in 22°C room.	Forearm water immersion provided better rate of cooling (p = 0.036)	No difference	NR	NR	NR	NR
Hemmatjo et al. (2017)[17]	n=15 Simulated firefighting activities in smoke-diving room 45-50 min	Randomized 1. no cooling device 2. cooling gel containing menthol 3. PCM cooling vest 4. cooling gel and PCM cooling vest	Temporal temperature significantly lower for the PCM cooling vest group ($P < 0.05$)	HR significantly lower for the PCM cooling vest group ($P < 0.05$)	NR	NR	NR	NR
Yeargin et al. (2016)[18]	n=38 Four 15-minute simulated fire drills	Randomized Head-cooling gel pack in helmet during simulation, or forearm-cooling in 5°C water during 15-minute recovery period.	Forearm cooling had better rate of lowering CT compared to control group (-1.61°C versus -0.23°C; P<.001)	No difference	Forearm cooling had lower PSI (-7.9) versus (-2.6) in the control group	NR	NR	NR
Walker et al. (2014)[19]	n=74 Two 20-min fire drills in climatic chamber.	Randomized Lower body immersed in cold-water 15°C or ingestion of 7 $g \cdot kg^{-1}$ of body weight crushed ice slush drink (–1 °C) during 15-minute recovery session (19°C).	CT significantly lower in cold-water immersion (–0.5 °C, 95% CI –1.0 to 0.0) and crushed ice slush drink (–0.5 °C 95% CI –0.9 to –0.2) groups compared to control	NR	NR	NR	NR	No difference in RPE

Chapter Three: Randomized Pilot Results

Abstract

Background: Adverse health effects among agricultural workers due to chronic heat exposure have been characterized in the literature as not only due to high ambient temperatures but also due to intensive manual labor in hot and humid conditions. The US Centers for Disease Control and Prevention reports that the average annual heat-related death rate among agricultural workers is nearly 20 times greater than that of the overall US workforce.

Methods: In April-May of 2018 and 2019 we conducted pilot studies in Florida, to examine workplace personal cooling gear interventions that could prevent HRI. A sample of 84 agricultural workers in Florida were randomized to 1 of 4 groups: 1) no intervention, clothing as usual; 2) cooling bandana; 3) cooling vest; and 4) both the cooling bandana and cooling vest.

Results: A total of 78 agricultural workers completed one intervention workday. Core body temperature differences were observed; the bandana group had 38% of participants exceeded 38.0°C, followed by 46% in the control group, 53% in combination group, and the vest group had the highest proportion with 60%. Logistic regression analysis revealed the bandana group had lower odds of exceeding a core body temperature of 38.0°C (OR 0.7, CI90 [0.2, 3.2]) and the vest group had higher odds of exceeding 38.0°C (OR 1.8, CI90 [0.4, 7.9). The use of both the cooling vest and bandana (combination group) showed the effect was little different from the control group (OR 1.3, CI90 [0.3, 5.6].

Conclusion: This is the first field-based study to pilot cooling intervention among agricultural workers in the US using biomonitoring equipment. This study found that agricultural workers that used a bandana while working in a hot environment has the potential to be protective against exceeding a core body temperature of 38.0°C.

Chapter Three: Cooling Interventions Among Agricultural Workers: A Randomized Pilot Study

This chapter provides quantitative results of a mixed methods study that piloted cooling interventions aimed at reducing heat stress experienced by agricultural workers from working in hot and humid outdoor conditions. The purpose of this study is to determine which intervention (a cooling bandana, a cooling vest, or the two together) is practical and effective to use while working, and the physiological response to using personal coo ling gear among agricultural workers.

Introduction

It is estimated that between 2-3 million[23] workers are employed in the US agricultural industry. Agricultural workers perform intense labor outside in direct sunlight and in humid environmental conditions exposing workers to a high risk of heat-related illness (HRI). The US Bureau of Labor Statistic reports agriculture is among the most dangerous industries.[79] Agricultural workers are at risk of heat related mortality 20 times greater than the general workforce population.[7] Adding to agricultural workers' vulnerability are rising temperatures and an increase in the frequency and intensity of heat waves.[80] This study builds on the results of the *Girasoles* Study which showed agricultural workers had moderate-to-vigorous activity under dangerously hot environmental conditions.[15,36] Intensive manual labor in hot and humid conditions resulted in 80% of agricultural workers exceeding the recommended internal core body temperature threshold limit value (38°C; 100.4°F) at least once during a three-day study period. In addition, 83% (n=198) of the enrolled agricultural workers reported one or more HRI symptoms while working.[15]

Heat-related illness (HRI) is defined as the elevation of core body temperature that exceeds the compensatory limits of thermoregulations from exposure to environmental heat stress and exertional heat.[8] HRI consists of symptoms that range from mild heat exhaustion to severe heat stroke and death. The combination of high environmental temperatures and intense physical activity can result in rapid onset of exertional heat stroke and is associated with higher core body temperatures.[18] Core body temperature is maintained roughly at 37°C. Once core body temperature reaches 38°C, heat exhaustion can ensue, potentially leading to heat stroke when core body temperatures reach or exceed 40°C.[8] The National Institute for Occupational Safety and Health (NIOSH) and The American Conference of Governmental Industrial Hygienists (ACGIH) recommend that core body temperatures not exceed 38°C in prolonged exposure to strenuous work (>2hours). The Occupational Safety and Health Administration (OSHA) recommends workers drink water and rest every hour in the shade long enough to recover from HRI.[19]

To date, only a few studies could be located in peer-reviewed literature that have assessed the impact of HRI intervention studies among agricultural workers. In El Salvador, a longitudinal study over a harvest period implemented a modified recommendation from OSHA's Water, Rest, Shade guidelines. This is the only field study conducted with agricultural workers examining the impact of interventions on HRI.[20] Agricultural workers (n=43) wore 3L backpacks with water, rested 15 minutes every hour in a shaded canopy that was moved through the field, and used an ergonomic machete for cutting sugarcane. Post-intervention results showed workers reported a decrease in HRI symptoms and increase in production from an average of 5.1 to 7.3 tons/person/day post intervention.[20] They did not determine which, if any of their intervention strategies, had the greatest impact of the water, rest, shade and machete. In Korea, 12 participants were randomized to multiple cooling devices that included bandanas, hat, vest, and combination groups during simulated red pepper harvest picking in a climatic chamber (WBGT33°C) for 120 minutes (two bouts of 50-min work with a 10 min rest).[21] The groups using a combination of cooling devices had no participants with rectal temperatures of ≥38°C.

Academic-community partnerships and the National Institute for Occupational Safety and Health (NIOSH) funded Centers for Agricultural Safety and Health have developed heat protection safety education programs for agricultural workers based on OSHA recommendations[19]; however, little is known about the effectiveness of these programs. Only two evaluations of safety education programs designed to prevent HRI among agricultural workers could be located in the peer-reviewed literature. In North Carolina, seven farmworker youth aged 14-20 years received HRI safety education, who then trained 147 farmworker youth on HRI safety.[81] The mean HRI safety knowledge pre-test score was 5.34 and the mean post-test score was 9 on a scale of 10. A 45-90 minute HRI training with agricultural workers showed it increased HRI safety and prevention knowledge from pre-test to post-test [$F(1, 120)=4.27$, $p < .05$].[82] Neither of the two studies reported if HRI symptoms improved while working after safety education.

Cooling vests that either recirculate liquid ice-chilled coolant or use phase change materials (PCM) have been used to reduce heat strain in construction workers, industrial workers, and firefighters, with mixed results. PCM is a substance that absorbs heat during the process of changing from a solid frozen state to melting into a liquid state. PCM is able to absorb more heat and takes longer to melt than liquid coolant, maintaining a constant cooling temperature longer. Cooling vests with PCM inserts were used by construction workers during the workers' scheduled two to six rest times, each of which ranged from 15-30 minutes. Heart rate in the intervention group was lower compared to the control group.[52,57,62] A study with 15 firefighters in Iran showed heart rate and temporal temperature were significantly lower in the PCM vest group ($P < 0.05$).[65] Vests that recirculated liquid ice-chilled coolant via a small battery-operated motor pump was evaluated in 12 male graduate students who simulated 30 minutes of power utility tasks outdoors[59] and in 20 college-aged, non-smoking, healthy males who simulated industrial work.[53] Higher productivity was reported compared to those not using a cooling device outdoors ($p = .011$),[59] and those using the devices had lower rectal temperatures than the control group ($p < 0.05$).[53] Forearm immersion in cold water, or lower body immersion in cold-water (water temperature ranged 5°C to 20°C), in firefighter studies reported significant reduction in core temperature during post-fire recovery.[54,67-69]

As of yet, there are no field-based US studies of cooling interventions to protect agricultural workers from HRI symptoms or from exceeding core body temperature thresholds. Educational programs and campaigns to drink more water or rest in the shade will not necessarily attenuate the occurrence of HRI. Based on studies using multiple cooling devices and the positive results of cooling vest occupational studies in China, Iran, and India, this field-based study examined a cooling bandana and cooling vest worn by agricultural workers while working in hot and humid conditions outdoors. Previous studies of cooling devices among workers have used the devices during regularly scheduled work breaks. Our population of agricultural workers, similar to the majority of agricultural workers in the US, do not have scheduled or mandatory work-rest cycled breaks. Therefore, out protocol was designed to test the devices while workers were in the fields. This paper describes the field-based pilot study conducted to examine the effectiveness and practicality of cooling devices. The study design was guided by components of the Farmworker Vulnerability to Heat Hazards Framework, specifically focusing on the adaptive capacity to improve heat stress response and maintain physiological equilibrium.[37] It was hypothesized that the use of cooling devices while working would attenuate rises in core body temperature and decrease self-reported HRI symptoms.

Methods

Design and participants

In April-May of 2018 and 2019 we conducted pilot studies among agricultural workers in Homestead and Pierson, Florida, to examine workplace personal cooling gear interventions that could prevent HRI without interfering with daily work routines. The Institutional Review Board at

Emory University provided approval for the study and all participants provided informed consent to participate in the study. Each participant received a $50 gift card for their participation in the intervention study at the end of their exit interviews.

In collaboration with the Farmworker Association of Florida (FWAF), a convenience sample was recruited by trained community health workers through phone calls and community events organized by the FWAF and other grassroots organizations. Workers were eligible to participate if they were: male or female, between 18-54 years of age, and working in the agricultural sector for at least the last four weeks. Exclusion criteria included workers who reported being pregnant or had diabetes mellitus type I. We enrolled participants in small cohorts of 6-12 workers for a total of 84 participants for a baseline visit, followed by a workday where cooling interventions were compared.

Randomization

Participants were randomized to 1 of 4 groups: 1) no intervention, clothing as usual; 2) cooling bandana; 3) cooling vest; and 4) both the cooling bandana and cooling vest. A computer-generated block randomization schedule provided a priori by the study biostatistician, which remained concealed until participants were randomized after enrollment. Research staff and participants remained blinded to group allocation until the pre-work visit when participants arrived at the FWAF office the morning of the study workday.

Figure 1. Cooling Vest

Intervention

An important component in selecting the cooling devices to be examined was that the devices allowed free range of motion and unrestricted mobility while the participants worked in agricultural fields. Cooling devices in this pilot include the TechNiche Elite Hybrid Cooling Vest (Vista, CA, Figure 1) which includes cooling inserts and weighs 5 pounds. The hybrid vest uses PCM cooling for heat stress relief and is designed for both humid and dry hot climates. Participants who were randomized to use a vest received a second pair of frozen inserts in a bag that kept them frozen and ready to replace once the first set of inserts melted. The PCM inserts remain at 58°F (14°C) for up to 3-5 hours. During the phase change of solid to liquid of the PCM inserts, more energy (heat) is needed to melt the inserts; thus, providing longer cooling effects. This vest was chosen since phase change materia has been used in previous occupational group studies.[52,62]

The Chill-Its® 6700CT Evaporative Cooling Bandana with Cooling Towel (Ergodyne, St. Paul, MN, Figure 2), constructed with polyvinyl acetate (PVA) material, is the second device we examined, which is easy to use, affordable, and reusable. Participants saturate the bandana in water for 1 minute to active it, twirl the bandana to remove excess water, and tie the bandana around their head or neck for 4 hours, and repeat the steps during break every ~4 hours or as needed to maintain the cooling effect. Cooling devices maintain their cooling effectiveness for ~4 hours due to a high-water absorption capability and efficient water evaporation.

Figure 2. Bandana

Procedure

At baseline, participants were administered the Occupational Heat-Related Illness Questionnaire which includes demographic and work practice questions. Anthropometric measurements such as height, weight, body fat, and blood pressure were also recorded. Participants were then given a CorTemp® pill sensor to swallow during dinner that evening and were asked to return the following day before starting their work shift.

On the day of the intervention, participants met us at the FWAF office before starting their work shift. At this visit we obtained blood and urine samples from the participants and equipped them with biomonitoring devices. Biomonitoring equipment worn by the participants included: 1) a CorTemp® Data Recorder (HQInc., Palmetto, Florida) to record core body temperature from the

CorTemp® pill sensor; 2) the Polar® T31 heart rate transmitter belt; and 3) an ActiGraph™ GTX3+ (ActiGraph, LLC, Pensacola, Florida) to capture physical activity. Participants were given instructions on the use of the cooling devices if randomized to an intervention group. At the conclusion of the workday, study participants returned to the FWAF office for post-workday blood and urine sample collections and for removal of the biomonitoring equipment. The FWAF's community health workers administered a post-work survey and exit interview. All surveys and individual blood and urine results were provided in the participant's primary language.

Measures

Heart rate was simultaneously recorded via a heart rate transmitter belt (Polar® T31) at 30-second intervals. Heart rate monitoring downloaded results were visually inspected by work hour and by individual participant as a quality-control check and examined for physiologic plausibility.

A triaxial accelerometer (ActiGraph™ GTX3+, Pensacola, Florida) was worn by participants on their right hip on an elastic waistband. The ActiGraph recorded accelerations on three individual planes every 30 seconds. Each ActiGraph was initialized with the assigned participant's sex, height, weight, and age. We used the same accelerometer data-processing methods used in the *Girasoles* study.[36] Vectors of magnitude count per minute (CPM) were derived from raw vector magnitude counts for every 30 seconds and summed into 1-minute counts. All vectors of magnitude count per minute were visually inspected by work hour and by individual participant as a quality-control check. To determine intensity of work activity, we summed all of the minutes which met the following established criteria:

Sedentary activity: 0 to < 200 CPM

Light activity: 200 to < 2690 CPM

Moderate to vigorous activity: ≥ 2690 CPM

Environmental heat stress work conditions were calculated by using the Homestead and Pierson weather station of the Florida Automated Weather Network (FAWN) which collects readings every 15 minutes. Ambient temperature and relative humidity—from the FAWN—were used both to calculate the heat index and estimate the wet bulb globe temperature in the sun (WBGT). This helped to establish data about participants' environmental conditions on workdays in which they were observed.

Outcome variables

Core body temperature was continuously recorded by an ingested CorTemp® temperature sensor (CoreTemp HQ Inc., Palmetto, Florida) at 30-second intervals. The ingested CorTemp® temperature sensor transmits through the gastrointestinal tract to an external CorTemp® Data Recorder (HQInc., Palmetto, Florida) worn around the participant's waist. We followed the cleaning and analytic methods established by Hertzberg et al[83] for continuous core body temperature data. Participants who had 2 consecutive 30 second readings of core body temperatures over 38.0ºC were considered to have exceeded the recommended limit. We then added the sum of all instances that a participant's core body temperature exceeded 38.0ºC to obtain time spent above the limit. In addition, core body temperature files were truncated to the worker's self-reported workday start and stop time. Core body temperature files with ≥ 20% of missing data were removed because of the likelihood it being due to faulty devices.[83] We also excluded two core body temperature files where the sensor was excreted more than 20 minutes before the end of the workday. A core body temperature change of ≥5 degree difference between nearest data points was considered an implausible change and set to missing.[83]

HRI symptoms were assessed during the post-work survey. Participants were asked if they experienced any of the following forms of HRI while working: Excessive sweating, headache, nausea or vomiting, confusion, dizziness, fainting, and sudden muscle cramps. Responses were recorded as a "yes" or "no." Participants' "yes" responses to each symptom were summed and reported as the sum of HRI symptoms experienced for the observed workday.

Statistical analysis

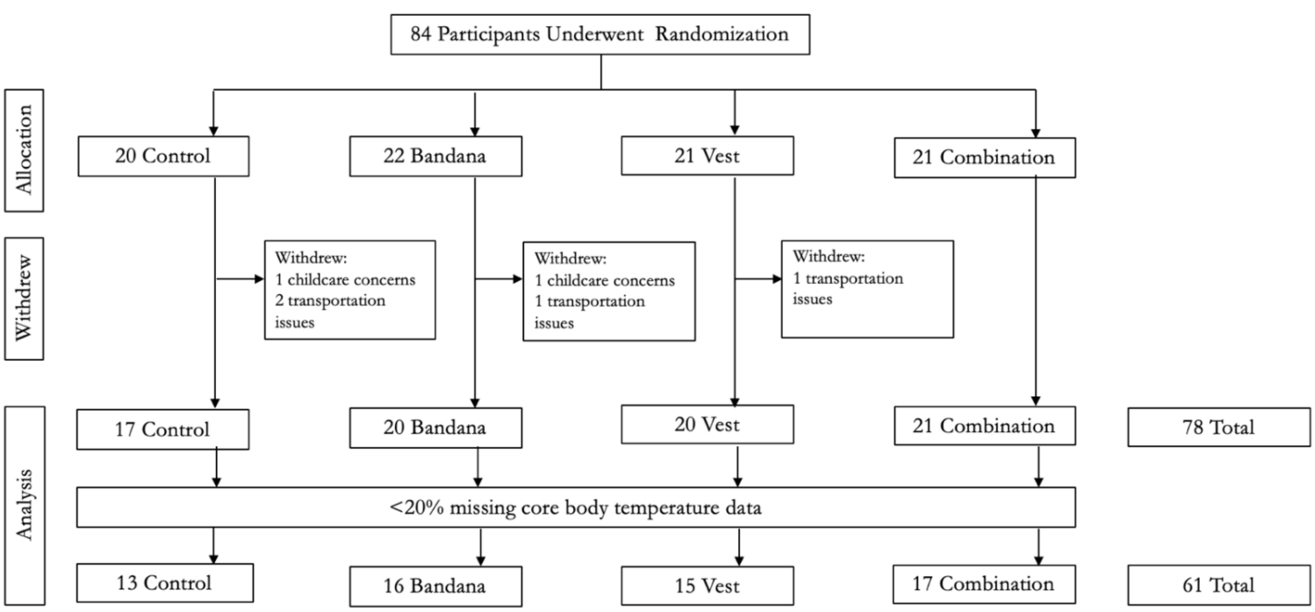
Continuous variables were summarized as mean ± SD or median (IQR), as appropriate, and categorical variables were reported as count and percentage (%). We included core body temperature, heart rate, and accelerometer data only if it occurred between a worker's self-reported workday start and stop time and < 20 percent of the total data for each participant were missing (Figure 3).

A logistic regression model was built to assess the effect of cooling interventions to prevent core body temperature from exceeding 38.0ºC core body temperature (Yes/No). Five possible confounders (BMI, workday duration, years working in US agriculture, maximum heat index, and moderate-vigorous physical activity during work hours) were assessed by entering them into the logistic regression model one at a time. In the *Girasoles* Study we found BMI, years worked in agriculture, moderate-vigorous physical activity, and maximum heat index to be associated with exceeding a core body temperature of 38.0ºC. The unadjusted and adjusted odd ratios (ORs) were then compared. The unadjusted and adjusted ORs and 90% confidence interval (CI) for the models are presented in the results. Due to the small sample, we limited the maximum model size to one confounder. Statistical significance was set at the 5% level. All statistical analysis was performed on SAS version 9.4 (Cary, NC).

Results

A total of 84 workers were randomized to one of three intervention groups and a fourth control group (Figure 3). Of the 78 participants who completed one workday trial, 20 were in the bandana group, 20 in the vest group, and the combination (bandana and vest) group had 21 participants, and the control group had 17 participants. Participants that withdrew from the study after baseline was due to transportation issues and childcare concerns. There were 61 participants who had < 20% core body temperature files missing. The overall sociodemographic, anthropometric, and work characteristics of the sample are reported in Table 1. The mean age of the participant was 42 (standard deviation [SD], 9), average years of education was 6 (SD, 3), and the majority were female (66%) from Mexico (79%). Mean body mass index (BMI) was 31 (SD, 7), 18% reported a history of hypertension and 11% reported a medical history of diabetes mellitus type 2. The mean maximum heat index to which participants were exposed ranged from 86°F to 89°F and mean maximum relative humidity was 82% to 84%. Of the 84 workers that enrolled, 35 worked in ferneries, 34 in nurseries, 10 with field crops, and 5 in landscaping. The mean years in agriculture was 17 (SD, 9), and the median workday was 8.2 hours long.

Figure 3. CONSORT flowchart of the study



*Participants did not know their assignment before dropping out

Table 1. Sample Characteristics

	Overall n = 84	Control n = 17	Bandana n = 20	Vest n = 20	Combination n = 21
Demographic	mean (SD) % (n) median [Q1, Q3]				
Age	42 (9)	42 (9)	45 (8)	41 (9)	43 7
Female	66% (55)	82% (14)	60% (12)	55% (11)	62% (13)
Years of education	6 (3)	6 (3)	7 (3)	7 (4)	7 (4)
Mexican nationality	79% (66)	88% (15)	95% (19)	65% (13)	88% (15)
Health					
Body mass index	31 (7)	31 (7)	32 (7)	31 (9)	30 (3)
Percent body fat					
Female	36% (7)	34% (10)	38% (6)	38% (7)	36% (3)
Male	26% (7)	25% (6)	30% (6)	23% (5)	25% (9)
History of Hypertension	18% (15)	24% (4)	20% (4)	15% (3)	15% (3)
History of Diabetes Type 2	11% (9)	12% (2)	20% (4)	5% (1)	5% (1)
Work					
Years worked in agriculture	17 (9)	17 (9)	20 (7)	13 (10)	13 (10)
Agricultural work type					
Fernery	42% (35)	47% (8)	40% (8)	45% (9)	38% (8)
Nursery	41% (34)	35% (6)	45% (9)	30% (6)	48% (10)
Crop	12% (10)	6% (1)	15% (3)	15% (3)	9% (2)
Landscape	6% (5)	12% (2)	-- --	10% (2)	5% (1)
Hours worked per day	-- --	7:50 [6:10-8:30]	8:10 [6:10-8:30]	8:40 [6:30-9:20]	8:00 [6:00-9:00]
Environment					
Ambient Temperature, (°F) max	-- --	85 (2)	85 (2)	86 (3)	84 (3)
Relative Humidity, (%) max	-- --	83 (11)	82 (11)	83 (11)	84 (8)
Heat index, (°F) max	-- --	89 (4)	88 (4)	89 (4)	86 (5)

Heart rate

Of the 78 participants who completed a workday trial, 68 participants included in the heart rate analysis had less than 20% of heart rate data missing (Table 3). Average heart rate did not differ significantly by intervention groups (Table 3).

Table 3. Summary of heart rate by intervention group, n=68*

		Heart Rate	
Cooling Intervention	n	mean	(SD)
Control	15	98	(12)
Bandana	20	101	(13)
Vest	16	102	(12)
Combination	17	98	(12)

* Sample sizes are smaller than the full cohort due primarily to loss of heart rate files to technical issues.

Physical Activity

Median counts per minute of vector magnitude and time spent per day in moderate-vigorous activity (2690 or higher counts per minute vector magnitude) did not differ significantly by intervention groups (Table 4). The median time spent in moderate to vigorous physical activity was greatest for the control group and least for the bandana group, although the difference was not statistically significant (165 and 90 minutes, respectively).

The pattern of physical activity over the course of the workday is shown in Figure 4. Median vector magnitude counts were higher in the first 4 hours (morning) of workshift than the last 4 hours (afternoon). A midday break is observed by the decrease of median vector magnitude counts for all groups. The control and vest group had more intense activity over the workday, while the bandana and combination group had less intense activity throughout the day.

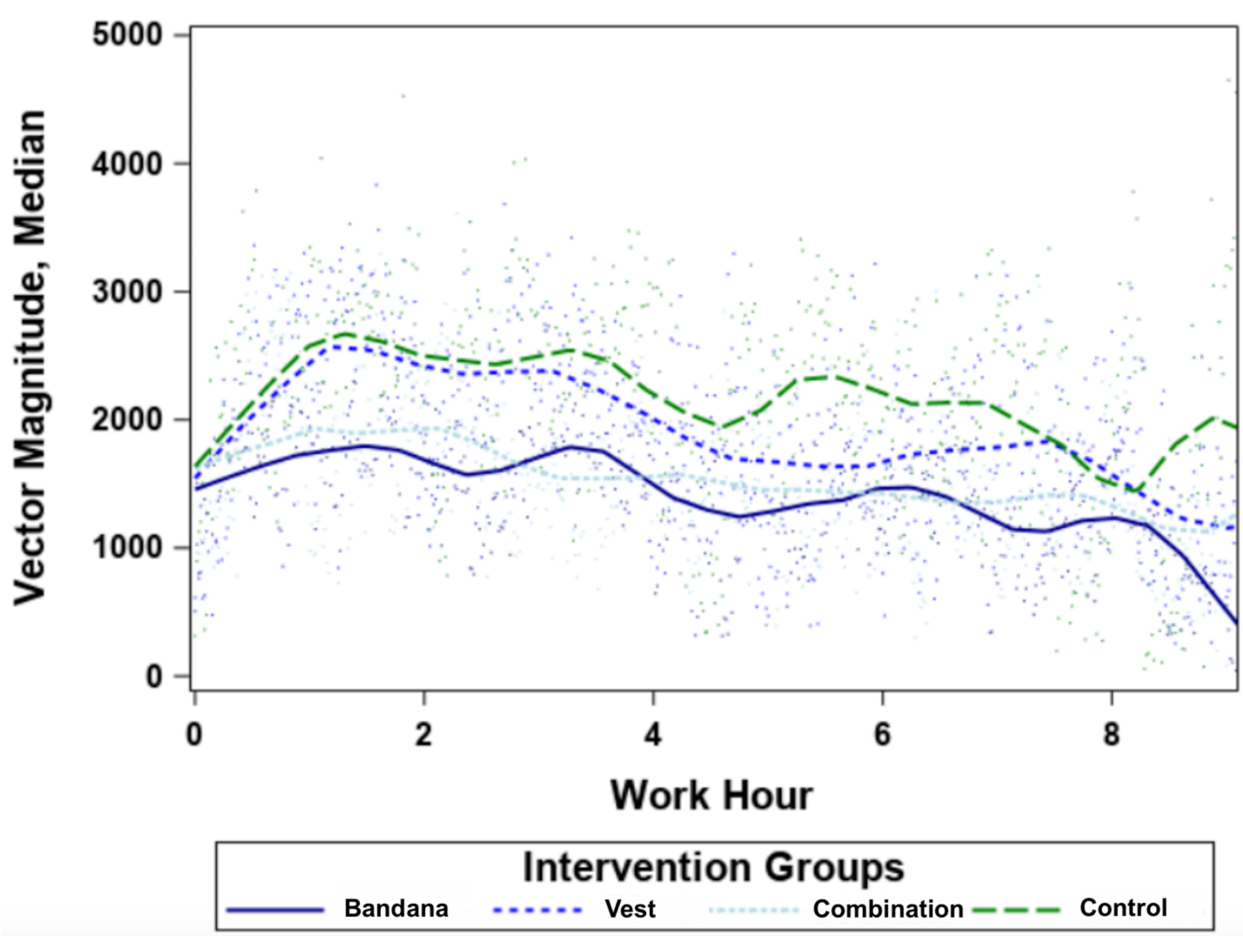
Table 4. Summary of physical activity measures of intervention group, n=70*

		Counts per minute vector magnitude		Minutes per day moderate-vigorous[a]	
Cooling Intervention	n	Median [Q1, Q3]			
Control	15	2098	[1637, 3646]	165	[99, 286]
Bandana	19	1647	[1360, 2254]	90	[57, 141]
Vest	18	2172	[746, 3809]	157	[40, 235]
Combination	18	1782	[1187, 3746]	111	[59, 246]

*Sample sizes are smaller due primarily to loss of accelerometer files to technical issues.

[a]Activity levels are defined as the following vector magnitude counts per minute cutoffs: sedentary: 0 to less than 200; light: 200 to less than 2690; moderate to vigorous: 2690 or higher.

Figure 4. Physical activity over the course of the workday



HRI symptoms

Seventy-four participants answered question about HRI symptoms experienced throughout the workday. Figure 5 shows the combination group had the highest proportion of participants reporting no HRI symptoms, followed by the bandana group, vest group, and the control group had the least participants reporting no HRI symptoms (80%, 68%, 60%, and 47%, respectively). The bandana group reported 3 types of symptoms experienced: muscle cramps (5%), excessive sweating (26%), and 10% reported nausea (Table 5). The vest group reported 5 different HRI symptoms, the combination group reported 3 different HRI symptoms, while the control group reported 4 different HRI symptoms. None of the groups reported fainting; however, one participant in the control group reported experiencing confusion, and the vest and combination group each had one participant report dizziness. Excessive sweating was the primary symptoms reported by the four intervention groups. No significant differences were observed.

Figure 5. Sum of HRI symptoms by intervention, n=74

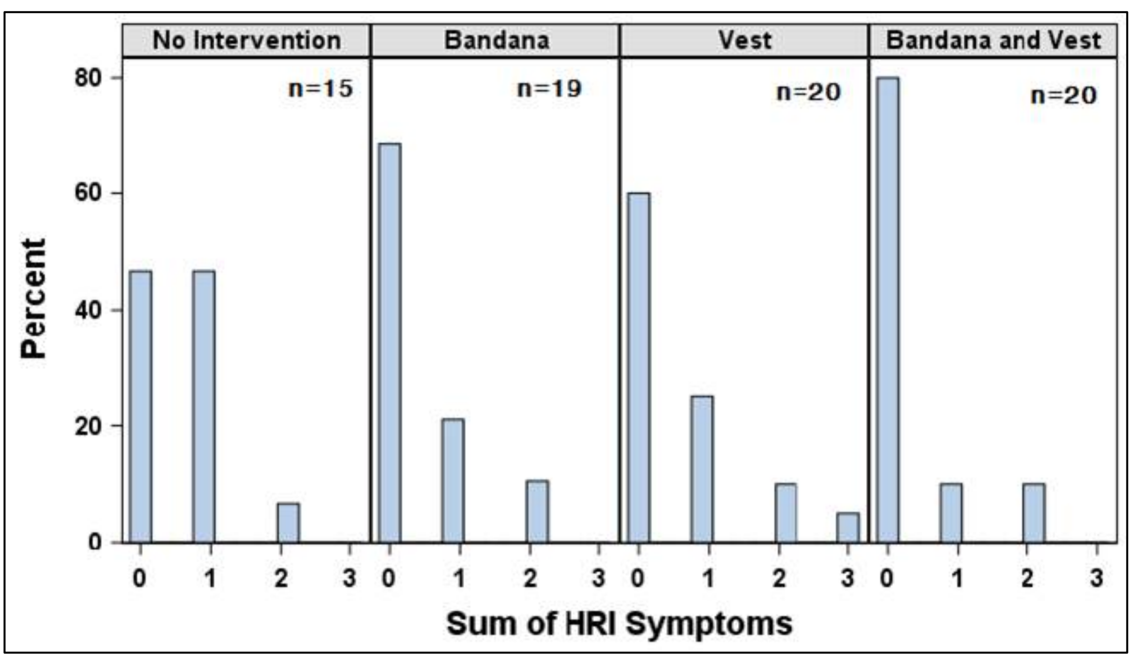


Table 5. Summary of symptoms reported, n=74*

	Control n = 15		Bandana n = 19		Vest n = 20		Combination n = 20	
Symptom Type, % (n)								
Excessive Sweating	40%	6	26%	5	20%	4	10%	2
Muscle Cramps	7%	1	5%	1	5%	1	--	--
Headaches	13%	2	--	--	20%	4	10%	2
Nausea	--	--	10%	2	10%	2	--	--
Dizziness	--	--	--	--	5%	1	5%	1
Confusion	5%	1	--	--	--	--	--	--
Fainting	--	--	--	--	--	--	--	--

*Post workday surveys missing

Core body temperature

Core body temperature analysis included data from 61 participants who had less than 20% of core body temperature readings missing (Table 6). Core body temperature differences were observed; the bandana group had 38% of participants exceeded 38.0°C, followed by 46% in the control group, 53% in combination group, and the vest group had the highest proportion with 60%. The median time spent over 38.0°C was 23 minutes (Interquartile Range [Q1, Q3],16, 32) for the bandana group. The control group median time spent over 38.0°C was 26 minutes [13, 188], followed by the combination group with a median of 32 minutes [21, 78], and the vest group had the highest amount spent with 53 minutes [13, 188].

Table 6. Summary of core body temperature, n=61*

		> 38.0°C		Minutes > 38.0°C	
Cooling Intervention		%	(n)	Median	[Q1, Q3]
Control	13	46%	6	26	[1, 66]
Bandana	16	38%	6	23	[16, 32]
Vest	15	60%	9	53	[13, 188]
Combination	17	53%	9	32	[21, 78]

* Sample sizes are smaller than the full cohort due primarily to loss of core temperature files to technical issues.

Logistic regression analysis revealed the bandana group had lower odds of exceeding a core body temperature of 38.0°C (OR 0.7, CI90 [0.2, 3.1]) and the vest group had higher odds of exceeding 38.0°C (OR 1.8, CI90 [0.4, 7.9). The use of both the cooling vest and bandana (combination group) showed little effect compared with the control group (OR 1.3, CI90 [0.3, 5.6]. Body mass index, maximum heat index, years working in agriculture, primary work type, hours worked, and moderate-vigorous activity did not confound our estimates (Table 7). Although these results are not significant, we found that the bandana remained protective both in the unadjusted and adjusted models.

Table 7. Odd Ratio of exceeding Core body temperature 38.0°C, n=61*

	Unadjusted	Adjusted				
		BMI**	Heat Index Max**	Years worked in agriculture**	Hours worked per day**	Moderate-vigorous activity**
Cooling Intervention		OR [*CI.90*]				
Bandana	0.7 [0.2, 3.1]	0.9 [0.2,3.2]	0.7 [0.2, 2.6]	0.6 [0.2, 2.3]	0.8 [0.2, 2.6]	0.9 [0.3, 3.5]
Vest	1.8 [0.4, 7.9]	2.5 [0.6, 9.9]	1.6 [0.4, 5.9]	1.7 [0.5, 5.9]	1.8 [0.5, 6.4]	1.8 [0.5, 6.4]
Combination	1.3 [0.3, 5.6]	1.5 [0.4, 5.2]	1.7 [0.5, 6.3]	1.3 [0.4, 4.3]	1.4 [0.4, 4.8]	1.3 [0.4, 4.5]

* Sample sizes are smaller than the full cohort due primarily to loss of core temperature files to technical issues.
**OR reported are after adjusting for individual variable.

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Discussion

This is the first field-based study to pilot cooling intervention among agricultural workers in the US using biomonitoring equipment. This randomized trial showed the bandana was protective against exceeding a core body temperature of 38.0°C compared to the other groups; although, not statistical meaningful due to insufficient power. Nonetheless, we are encouraged with the results of the bandana group, in which nearly 70% of the workers did not report any HRI symptoms.

The bandana is light weight and can be worn with little restriction to body movement. For agricultural workers who have physically demanding jobs that requires a full spectrum of movement, comfort of personal cooling devices is critical for usage. Anatomically the neck area has large blood vessels close to the skin which is optimal for heat removal and may explain the reason for fewer participants exceeding 38.0°C in this group.

Studies with construction workers using cooling vest during their scheduled rest breaks[52,62] and while working[57] have shown the cooling vest to be effective at mitigating heat stress. However, we did not observe the cooling vest to mitigate heat stress in our sample of agricultural workers. The odds of exceeding a core body temperature of 38.0°C increased 80% if the vest was used while working. The vest group was the only group to report feeling 3 or more HRI symptoms. There are differences in the study design that could contribute to the different outcome compared with other studies. Primarily, the agricultural workers in our study do not have regularly scheduled rest breaks as the construction workers do in the studies conducted in China. Studies that have assessed cooling vests while working in the construction,[57] agricultural,[21] and foundry[58] sectors used the vest for about 2 hours—not an entire work day as the participants in our study. Thus, cooling vests may be more practical and effective to use during regularly scheduled rest breaks. However, using the cooling vest during rest breaks may not be feasible if regularly scheduled breaks are not a routine of the workday. Anatomically, whereas the neck area has larger veins and less adipose tissue, the torso area has smaller veins and more adipose tissue, which may limit the effectiveness of the cooling vest to maintain workers' cool. The vest was also worn *over* one layer of clothing whereas the bandana was placed around the neck touching the skin directly. Moreover, the 5 lbs of additional mass to the worker may result in more physiologic strain while working.

In a study by Choi et al. (2008) with red pepper pickers, those who wore two cooling devices while working in a chamber did not exceed rectal temperatures of ≥38°C. In our study, the combination of using a cooling vest and bandana was not protective against exceeding a core body temperature of 38.0°C; although, they are the group with most participants reporting not experiencing any HRI symptoms during the workday. The differences between the Choi et al (2008) study and ours is that our participants worked on the field for an average of 8 hours while the red pepper pickers simulated working in a controlled climatic chamber for 120 minutes with a rest break.

Implications for Research

Future studies should include larger studies with economic evaluations to measure productivity and a cost-benefit analysis to determine whether the short and long-term benefits of investing in cooling gear outweigh the cost of implementation. Further research on cooling devices with direct contact with major blood vessels is also needed. Future research should also include an assessment of hydration as it is an important factor in reducing the risk of heat stress.

Limitations

This study had a small sample size that was further decreased in size during the analysis phase due primarily to loss of core temperature files to technical issues. The control group also had fewer participants due to workers withdrawing from the study. A convenience sample of agricultural workers in central and south Florida were randomly assigned into the intervention groups or control group, which may restrict the external validity of this study. Although the randomization was thought to be successful in creating the intervention and control groups with similar baseline characteristics, the vest and control group had higher physical activity compared to the bandana and combination group over the course of the workday, which was likely due to chance. However, its impact on the internal validity of the findings is likely to be limited because, based on logistic regression analysis, the results revealed that physical activity had no significant effect on exceeding a core body temperature of 38.0°C (Table 7). Despite limitations, this pilot study has an important strength which is that it was conducted in real work conditions with agricultural workers during one full workday.

Conclusion

This study found that agricultural workers who used a bandana while working in a hot environment may have been protected against exceeding a core body temperature of 38.0°C. Comprehensive empirical study on a large-scale are needed to determine if using a cooling bandana and other cooling interventions improve long-term health outcomes and work performance, have potential cost-savings, and reduce the risk of heat-related morbidity and mortality. If cooling interventions are shown to be feasible and effective across diverse outside occupational groups, this innovative intervention could improve working conditions for vulnerable occupational groups at risk of increased ambient temperature due to climate change, such as agricultural workers, and improve their health outcomes. Heat-related morbidity and mortality is preventable, and vulnerable occupational groups merit protection.

Chapter Four: Qualitative Pilot Results

Abstract

Background: Agricultural workers perform intense labor outside in direct sunlight and in humid environmental conditions exposing workers to a high risk of heat-related illness (HRI). To implement effective cooling interventions in occupational settings, it is important to consider workers' perceptions. To date, an analysis of agricultural workers' experience and perception of cooling devices used in the field while working has not been published.

Methods: Qualitatively data from 61 agricultural workers provided details of agricultural workers' perceptions and experiences with cooling interventions.

Results: Bandana group participants reported the bandana was practical to use at work, did not require excessive effort, and did not interfere with their work routine. Cooling vest group participants agreed that the vest was effective at cooling them but the practicality of using the vest at work was met with mixed reviews.

Conclusion: The findings of this qualitative study support and extend existing research regarding personal cooling and heat prevention research interventions with vulnerable occupational groups. Personal cooling gear was well received and utilized by the agricultural workers. Sustainable heat prevention studies and governmental protection strategies for occupational heat stress are urgently needed to reduce the risk of heat-related morbidity and mortality and projected climate change health impacts on outdoor workers.

Chapter Four: Cooling interventions among agricultural workers: Qualitative Pilot Results

This chapter develops qualitative features of a mixed methods study that piloted cooling interventions aimed at reducing heat stress experienced by agricultural workers from working in hot and humid outdoor conditions. The purpose of this chapter is to explore participants' perceptions on the practicality and effectiveness of the cooling interventions as well as to explore the perspective of current employer heat protection practices or lack thereof and propose heat protection practices that would help mitigate heat stress exposure.

Introduction

Adverse health effects among agricultural workers due to chronic heat exposure have been characterized in the literature as not only due to high ambient temperatures but also due to intensive manual labor in hot and humid conditions. The number of days with minimum temperatures above 75°F has doubled in the US Southeast as compared to average temperature from 1901-1960, and it is projected to have longer summer heat waves.[6] This study builds on the *Girasoles* Study, initiated in 2014 in partnership with the Farmworker Association of Florida (FWAF) in response to the Florida agricultural community's ongoing concerns about the impact of chronic heat exposure on their health.[11,17]

Florida currently has no heat illness prevention regulations, and studies have reported agricultural workers suffer from heat-related illness (HRI) and health effects such as elevated core body temperature, dehydration, and acute kidney injury while laboring in hot and humid conditions.[16,17] In addition, 83% (n=198) of enrolled agricultural workers in a study reported one or more HRI symptoms while working and some workers continued to work at moderate-to-vigorous activity under dangerously hot environmental conditions.[15,36] Similar reports of elevated core body temperature, acute kidney injury, and dehydration have been described in California, despite that state's heat illness prevention regulations.[32,72,84] In California's Central Valley, 8.3% agricultural workers in a study experienced a core body temperature ≥ 38.5°C (101.3°F)[32] while a study in Florida found that 23% of the agricultural workers studied experienced a core body temperature ≥ 38.5°C (101.3°F)[72] on at least one monitored workday. Both rates exceed recommendations from the World Health Organization (WHO), National Institute for Occupational Safety and Health (NIOSH), and American Conference of Governmental Industrial Hygienists (ACGIH) that core body temperatures should not exceed 38ºC in prolonged (>2 hours) exposure to strenuous work.

Only a few empirical studies have assessed the impact of cooling interventions on mitigating the adverse health effects of occupational heat stress in agricultural workers.[20,21] In El Salvador, a longitudinal study during a harvest period implemented an intervention with modified recommendations from Occupational Safety and Health Administration's (OSHA) Water, Rest, Shade guidelines. This is the only known or published field study conducted with agricultural workers examining the impact of interventions on HRI and renal function. [20,51] Agricultural workers wore 3L backpacks with water, rested 15 minutes every hour under a canopy that was moved through the field, and used an ergonomic machete for cutting sugarcane. Post-intervention results suggested a decrease in HRI symptoms among workers and lower decline in estimated glomerular filtration rate (eGFR). [20,51] In Korea, 12 agricultural workers were randomized to multiple cooling interventions that included bandanas, hats, vests, and combination groups of bandanas, hats, and vests.[21] The agricultural workers simulated red pepper harvest picking in a climatic chamber (WBGT33°C) for 120 minutes (two bouts of 50-min work with a 10 min rest). The cooling devices combination groups had no participants with rectal temperatures of ≥38°C.[21]

To implement effective cooling interventions in occupational settings, it is important to consider workers' perceptions. Interventions may be effective in reducing core body temperature, but if they are not acceptable to workers there is little likelihood that there will be widespread adoption. To date, an analysis of agricultural workers' experience and perception of cooling devices used in the field while working has not been published. This chapter describes qualitative features of a mixed methods study that piloted cooling interventions for agricultural workers. The interventions aimed to reduce workers' experiences of heat stress from working in hot and humid outdoor conditions. The purpose of this chapter is to explore participants' perceptions on the practicality and effectiveness of the cooling interventions. It also explores workers' perspectives of current employer implemented heat protection practices and propose heat protection practices that would help them mitigate heat stress exposure.

Methods

This study involved community-engaged research conducted in partnership with the FWAF. Emory University and FWAF have partnered for over 10 years in community-engaged research studying the physiological effects of chronic heat exposure among Florida agriculture workers. The FWAF is a grassroots organization whose staff has been trained in human subjects research. Many FWAF staff members were once agricultural workers. In April-May of 2018 and 2019 we conducted pilot studies in Homestead and Pierson, Florida, to examine workplace personal cooling gear interventions that could prevent HRI without interfering with daily work routines. To qualitatively explore agricultural workers' perceptions and experiences with cooling interventions, we conducted exit interviews with participants who were randomized to cooling interventions. The Institutional Review Board at Emory University provided approval for the study and all participants provided informed consent to participate in the study. Each participant received a $50 gift card for their participation in the intervention study and exit interviews.

We enrolled small groups of 6-12 participants for a baseline visit, followed by one pre-workday and one post-workday visit. On the pre-workday visit, participants were randomized to 1 of 4 groups: 1) no intervention, clothing as usual; 2) cooling bandana; 3) cooling vest; and 4) both cooling bandana and cooling vest. Cooling gear used in this pilot were 1) the HYPERKEWL™ Evaporative Cooling Hybrid Elite Sport Vest and 2) the Chill-Its® 6700CT Evaporative Cooling Bandana with Cooling Towel (Ergodyne, St. Paul, MN, Appendix C). The hybrid vest uses phase change material (PCM) cooling for heat stress relief and is designed for both humid and dry hot climates. Participants were instructed to place the 1st set of PCM inserts in the vest prior to wearing it and then remove them at lunch time or once inserts had melted and replace with the 2nd set of PCM inserts. The PCM inserts' cooling effect lasts about 3-5 hours. This vest was chosen as it uses PCM technology, which is the same technology used in field-based studies with construction workers.[52,62] The second type of gear was a cooling bandana constructed from reusable, affordable, and easy-to-use polyvinyl acetate material. Participants saturated the bandana in water for 1 minute to activate it, twirled it to remove excess water, and tied the bandana around their forehead or neck, repeating as needed to reactivate cooling properties of the bandana. At the end of their workday, participants returned to the office where a FWAF staff member conducted an exit interview in Spanish about the worker's perceptions on the practicality and effectiveness of the cooling gear, perspectives of current employer implemented heat protection practices, and potential heat protection practices they believed would help them mitigate heat stress exposure. Example questions included: "Was the time it took to put on the cooling equipment acceptable?" "Was it practical to use it at work?" "Did you feel comfortable using the cooling device?" "Would you recommend it to your friends? How would you convince them to use it?" Questions about workers' perspectives of current employer implemented heat protection practices included: “What practices does your company currently have to protect you against heat stress?” “What other practices do you think your company should implement to protect you against heat stress?”

Interviews were recorded and transcribed verbatim. For those who declined to be recorded, notes were taken by hand. After the interviews were transcribed, we reviewed all responses and initially coded data to identify categories and patterns. Next, we reviewed the results of initial coding and consolidated the most significant categories into key themes. The following code words were used to further categorize the data and identify key themes: **device_practicality** (practicality issues related to using devices while working, interfering with work routine, comfort of using devices); **device_effectiveness** (perceived effectiveness of maintaining workers’ cool). For current and proposed work heat protection practices, the following code words were used **current_protections** (current work heat protections practices); **needed_protections** (heat protections practices workers believe would protect them against heat stress); **barriers_protections** (barriers to work heat protections practices).

Results

The following results from the exit interviews describe the five major themes related to the practicality and perceived effectiveness of the cooling devices, workers’ perspectives of current employer heat protection practices, and proposed heat protection practices workers believe would help mitigate heat stress exposure. Participants labored in mean (standard deviation) ambient temperature of 85°F (3), relative humidity of 84% (10), and heat index of 88°F (4). A total of 61 participants provided exit interviews. Of these, 14 were in the bandana group, 15 in the vest group, 20 in the combination group, and 12 in the control group. The participants were 17 nursery workers, 31 fernery workers, 8 field crop workers, and 5 landscape workers. The mean (standard deviation) time working in agriculture was 16 (9) years, and the average level of education was 7 (4) years. The quotations are identified by a participant sex (M=Male; F=Female), primary industry, and age. To provide a general picture of the practicality of the cooling devices at work, participants were questioned about the use, comfort, and work interference of the cooling devices.

Practicality and Effectiveness of Cooling Bandana

Bandana group participants reported the bandana was practical to use at work, did not require excessive effort, and did not interfere with their work routine. Participants reported time to set-up bandana was acceptable. They saturated the bandana two to eight times during the workday with water located nearby, or from the bathroom facility.

"Yes. It was fast, just soak it and ... [makes a move to tie]" (f, nursery worker, 39).
"It was easy, because I carry water and I wet it [bandana] right there" (f, field crop, 36)

Two of the 14 participants in the bandana group reported that access to water to re-saturate the bandana was far from their work area. Even so, one of these participants reported re-saturating 3-4 times and the other 5-6 times during the workday.

"It wasn't that easy because the bathrooms are far away where I can get water" (f, nursery, 50).

All participants in the bandana group reported the bandana was comfortable to wear while working. The bandana was worn all day and many participants arrived with the bandana still on.

"I didn't feel it bothered me at all" (f, fernery, 51).
"I am still wearing it. I loved it so much that I'm still wearing it" (f, nursery, 50).
"I took it off once I arrived here" (f, nursery, 54).
"I haven't taken it off. I still have it on" (f, field crop, 53).

Participants in the bandana groups found the bandana kept them cool while working and those who used it on their foreheads said it also kept the sweat out of their eyes. All participants indicated they would recommend the bandana to their friends. They would encourage the use of the bandana by sharing their experience using the bandana and would allow their friends to try the bandana for themselves.

> *"It made me feel cool. I felt it didn't let my body temperature rise" (f, nursery, 50).*

> *"It is comfortable and helps us relax. You are cool. You don't feel you are suffocating from the heat" (m, nursery, 48).*

> *"It actually saved me from sweat going in my eyes" (m, nursery, 23).*

Practicality and Effectiveness of Cooling Vest

Cooling vest group participants agreed that the vest was effective at cooling them but the practicality of using the vest at work was met with mixed reviews. One participant said the time it took to switch the cooling inserts was long and not acceptable. Six of the 15 participants in the cooling vest group indicated the cooling inserts melted fast which caused the vest to feel heavy and uncomfortable to wear. However, they were all in agreement that the vest did keep them cool before the inserts melted.

> *"Basically, the ice lasted an hour. The moment the ice melted … its heavy and you can feel the weight… But wow, an effective way to keep us cool in this heat. It feels quite pleasant on the body" (m, nursery, 32).*

> *"I noticed that when I put on the vest . . . I felt cool. It cooled me so much, about two o'clock in the afternoon, when the heat began at that moment, then it was already melted, and it felt very hot. But when I changed the inserts, I got really cool. I felt amazing with the vest" (f, nursery, 36).*

All but one participant stated they would recommend the vest to their friends to use at work. However, several participants suggested the vest to be used only during periods when the temperature is very high to help recover from heat stress and cool them down.

> *"It did [interfere with the job routine] a little because we were bending, and you feel some extra weight. I liked it, but to use it in some moments, not all day" (m, nursery, 38).*

Practicality and Effectiveness of Cooling Bandana and Vest

Twenty participants were randomized to wear the cooling bandana and the vest. Most of these participants agreed the interventions were effective at keeping them cool.

> *"I felt like I had air conditioning on my body, you know, like a little air conditioning" (m, nursery,* 31).

> *"Well, I not only liked it, I loved that it kept me cool. With this heat I felt relief. I would like to continue using it more often. If you wear that vest it helps a lot, because it keeps you cool from the back and the front. Then the bandana helps a lot. In fact, I liked putting it here on my forehead than putting it on my neck. Yes, I felt better." (m, landscape, 31).*

The majority of this group's participants reported that the cooling bandana and vest were comfortable and practical to use at work although the vest was uncomfortable once it melted.

> *"When the ice runs out, it feels hot. Then you have to go to change the ice so that it feels cool again, because it has something that heats up too much. I don't know if it's the plastic, since it's not frozen" (f, nursery, 32).*

> *"I felt cool, a little heavy, but aside from that I felt very relaxed" (f, nursery, 43).*

The bandana was not used by two participants; one said she did not have access to water to re-saturate and the other said, *"since I don't sweat much, I didn't use it [bandana]"* (*m, nursery,* 46). Two of the participants only saturated the bandana once in the morning and did not re-saturate the bandana again during the work shift. Two participants reported using both interventions for only 10 minutes since they perceived the weather temperature was not hot enough to use the cooling devices. The remaining 14 participants used both cooling interventions and re-saturated the bandana multiple times without any barriers to water access. One participant removed the vest after 3 hours because, *"the cold, it makes me cough, and I started coughing and coughing, and then I took it off" (f, nursery, 41).*

Interestingly, three participants reported the vest provided back support and alleviated symptoms of muscle strain.

> *My waist hurt less, because sometimes when it's hot my waist hurts, but with that [vest], I don't" (f, nursery, 43).*
>
> *"When your back feels tired after a while, it [vest] actually feels pretty good on your back (f, nursery, 46).*

All but two participants said they would recommend the cooling devices to their friends and even suggested to their friends that they participate in the study in order to try out the cooling devices. One participant, who is a crew leader, said she would recommend the cooling devices to her friends and co-workers but voiced skepticism they would use cooling devices.

> *"I probably wouldn't be able to convince my workers. My workers are very hard-headed, but I can just tell them my experience from it" (f, nursery, 46).*

Current Occupational Heat Protection Practices

All participants including those in the control group were asked what heat protection practices are currently in place at their jobs. The majority responded with *"nada"* ("nothing"). Some workers reported their employer occasionally provides cool drinking water and ice. Others said their supervisors tell them to *"take it easy"* or take the day off if it is too hot.

> *"Just when we look bad, they [supervisor] tells us, 'better get out and sit over there until you feel better. If you feel better come back in. If not, just stay there'" (f, fernery, 46).*

However, no worker reported an official employer-implemented heat protection plan that provides a systematic guideline for drinking water or policy for taking breaks in the shade when the temperature reaches certain levels.

> *"Nothing, really. You gotta provide yourself" (m, fernery, 23).*
>
> *"Nothing, just an hour for lunch in the shade" (f, field crop, 49).*

Worker recommended occupational heat protection practices

When participants were asked what practices they thought employers should implement to protect them from heat stress, the primary answer was rest breaks followed by the provision of water, shaded areas to rest and have lunch, personal cooling devices, and heat stress prevention training and emergency aid training for heat stroke.

> *"That they give us breaks in the shade for about 15 minutes" (f, nursery, 37).*
> *"More breaks" (f, field crop, 49)*
> *"To be attentive at providing water and everything. Because where I work—not even water is given to us. We have to bring from our own house; we have to reach down into our pockets and purchase it with our earnings. And, for me, that's just not fair" (f, crop, 36).*
> *"Well, like that cooling vest, a good hat, a bandana, water to wash our hands, soap for when we go to eat and water to drink— separate from the water for our hands; portable toilets, which sometimes we don't have" (f, fernery, 50).*
> *"I believe that companies should give more information to workers, so we know—because people do not know how to react, when a person has heat stroke. They should train the crew leader to give people first aid when they see them sick. But if he [crew leader] doesn't know, then neither do the workers" (f, fernery, 42).*

Some workers expressed they didn't think there was anything that could be implemented to protect them from heat stress. Others said they did not know what practices could be implemented to protect them while working in the heat. One worker expressed that the onus is on workers for heat stress prevention.

> *"Well, working in the field is not easy to protect yourself from heat. Nothing can be done in the field" (m, fernery, 48).*
> *"I don't know" (f, nursery, 54).*
> *"We work out in the fields, and honestly, I think that it [heat protection practices] is our responsibility, you know" (f, fernery, 46).*

Participants were asked if they thought California's heat illness prevention regulations, which requires five-minute cool down rest breaks in the shade each hour, would work in Florida. The majority responded that heat illness prevention regulations would be beneficial to Florida agricultural workers.

> *"I say yes, because during June, July, and August, those are the hottest times. Then there are days when one is already like, tired, and nobody tells us, go in the shade, so we just keep working. It would be convenient for both workers and the employer. Well, I imagine. If they explained to us that when you feel hot to take a break and not wait for someone to experience fainting or something else. Instead, it's better to take a break." (m, field crop, 40)*

Participants also mentioned that having rest breaks in the shade each hour would increase productivity.

> *"Increasing the rest time, would reduce the working time, but even when the worker rests more, it is beneficial because the body recovers, with about 15 minutes it recovers a little. You start again and go again, but if work is constant, there comes a time when it throws you off, and the body feels it. Everyone says it, the body feels it in the afternoon. You don't work the same as in the morning" (m, landscape, 36).*

However, fernery workers, who are compensated by piece-rate, were hesitant about heat illness regulation that would require workers to take breaks that could negatively impact their wages.

> *"Well what we think about since we are paid very little by the [fern bunch], we have to hurry to make what we can that day. That is why many people do not want to go out to rest for a little while, in order to earn something, because it is very low paid, very cheap, and that's why" (f, fernery, 43).*

Barriers to occupational heat protection practices

Barriers to implementing occupational heat protection practices are the piece-rate compensation system, a lack of interest from employers, and a lack of regulations to protect them.

> *". . . when they need ferns, we have to work, no matter if it is hot, because we work for the piece, not by the hours" (f, fernery, 50).*
> *"I feel that in the years that I have been working, that there is not much attention to us, who dedicate ourselves to cutting fern here. That is, for the employer, his interest is profit, not the people. They don't worry about people" (m, fernery, 48)*

The lack of good will by employers to implement the OSHA's water, rest, and shade recommendations is another barrier which participants said could only be implemented through regulations.

"If it was a law, I think employers would respect the law" (m, nursery, 48).
"If it were law, it would be better, because there are places that the heat is extreme, unbearable that you can't stand it, but need makes you work in that heat" (f, crop, 49).

Although participants said they would use the cooling devices if the employer provided them, purchasing personal cooling devices for themselves would be a financial barrier.

"No. It would be too much" (f, nursery, 37).
"Maybe, but right now I don't have much money" (f, fernery, 46).

Discussion

This chapter provides insight into research that evaluated personal cooling device use among agricultural workers in Florida. We developed a cooling intervention study that focused on active cooling through individual use of cooling devices as a method to protect workers from heat stress. During semi-structured interviews at the post-workday visit, we assessed workers' views on the practicality and effectiveness of the cooling devices. We also asked workers about current work heat stress prevention practices at their place of employment, barriers to the implementation of heat stress preventions practices, and their views on heat stress prevention practices that should be implemented by employers.

The bandana group had the most positive responses to an intervention. While the vest and the combination group reported some discomfort with the vest, most agreed the cooling vest did help to cool them and was comfortable. These findings are consistent with the results of international studies in various industries with outside workers who reported that cooling bandanas and vests were comfortable and effective.[21,58,62] However, it is important to note that one study was done in a climatic chamber for 120 minutes while workers wore various cooling gear.[21] In another study, construction workers wore a cooling vest while working for 90 minutes.[58] In a third study, workers only used a cooling vest during their scheduled work breaks.[62] In our study, the workers wore the bandana and vest while working and without having regularly scheduled rest breaks. The vest was reported by a few workers to be uncomfortable and heavy once it melted, which suggests that using a cooling vest may be better suited to use during rest breaks. However, the challenge for agricultural workers in Florida (as in many parts of the country and the world) is that regularly scheduled rest breaks are not implemented by agribusiness nor government bodies. This keeps workers vulnerable to heat stress.

Agricultural workers are aware that they are uniquely vulnerable to heat stress and most are willing to use personal cooling devices to prevent heat stress, contrary to popular belief. [85] However, the cost of purchasing cooling devices is not perceived to be within their financial reach. Piece-rate compensation is another factor that makes agricultural workers vulnerable to heat stress because it pushes workers to forgo rest breaks in the effort to maximize the amount of daily compensation, as was voiced by piece-rate workers in our study. This observation is consistent with other studies.[9,86,87] Employers, however, frame piece-rate compensation as a system that provides workers with autonomy to pace themselves, take breaks as needed, and start and stop work at any time.[9]

Between 2000 and 2010, 29% of occupational heat-related deaths in the U.S. occurred in the Southeast, with the highest rates found in Hispanic male agricultural workers.[46] Looking ahead, it is projected that extreme heat in the southeast region will result in an average annual loss of 570 million labor hours.[6] Studies in the Southeast have reported that agricultural workers suffer from multiple HRI symptoms and acute health effects such as elevated core body temperature, dehydration, and acute kidney injury, while laboring in hot and humid conditions.[10,14,16,17]

Despite OSHA's heat illness prevention campaign promoting water, rest, and shade, studies show workers continue to experience HRI at concerning rates. This campaign is in addition to Section 5(a)(1) of the Occupational Safety and Health Act of 1970, which states that employers are required to provide a workplace that "is free from recognizable hazards that are causing or likely to cause death or serious harm to employees." This general clause, however, does not provide specific federal protection standards against the hazards of occupational heat exposure nor does it require employers to have a heat protection plan implemented for their workers. As such, the average annual heat-related death rate among agricultural workers is nearly 20 times greater than that of the overall US workforce.[7] When asked what could be done to prevent heat stress, some of the workers said, "nothing." This suggests that agricultural workers perceive their harsh working conditions as part as their daily lived occupational inequities.

In light of the existential threat of climate change, outdoor workers, such as agricultural workers, are at the forefront of being adversely impacted. It is critical that labor protection policies and occupational policies be implemented at the federal level to promulgate much needed protections for vulnerable occupational groups such as agricultural workers. NIOSH has evaluated scientific data on heat stress and the effects of working in hot environments to make recommendations for OSHA to adopt heat-protection standards in 1972, 1986, and in 2016.[22] In 2018, the CDC reviewed 25 outdoors HRI cases (14 resulted in fatalities) investigated by OSHA and suggested that extra precautions should be implemented when Heat Index reaches ≥85°F instead of the current OSHA recommendation Heat Index of >90°F.[88] Yet, no federal specific heat-protection standards exist. OSHA's resistance to implement heat-protection standards despite overwhelming evidence that outside workers are suffering and are projected to suffer even higher rates of heat stress calls for mitigation policy intervention. Public health professionals should actively engage with policy makers to implement regulations that protect the health and well-being of vulnerable occupational groups.

Implications for Research

Evidence-based research is also needed on heat stress protection interventions including personal cooling gear, heat stress prevention training, and emergency aid training for heat stroke. Although there have been some cooling interventions studies internationally, to date there are no published field-based cooling interventions with agricultural workers in the U.S. The findings of this qualitative research revealed that personal cooling gear was well received and largely utilized by the workers. Therefore, this demonstrates that intervention field-based research is feasible. An important factor to conduct better field-based research is partnering with the agricultural sector to engage in research at agricultural worksites. Future studies should also include economic evaluations to measure productivity and a cost-benefit analysis to determine if the short and long-term benefits of investing in cooling gear outweigh the cost of implementation.

Implications for Practice

At the individual level, rural and occupational nurses should assess workers' occupational heat prevention practices. Nurses should also provide education on methods to prevent HRI and recognize early signs and symptoms of HRI and on initiating treatment by moving an affected worker to a cool location to rest and ingest electrolytes.[18] At the sector level, occupational health nurses should also work with employers to implement a heat acclimatization plan which provides guidance about the gradual progression of time spent while working in the heat for all new employees.[18] In addition, crew leaders and supervisors should also be trained on recognizing signs and symptoms of heat stroke. They should also learn how to initiate on-site cooling by moving an affected worker to a cool location, beginning cold water immersion, or applying ice on the groin and axillae. Moreover, they should be prepared to call for emergency medical attention.[89] At the national level, nurses have a responsibility to collaborate with public policy officials. For example, nurses should help officials understand the impact of climate change on human health as well as the lack of regulatory protections for outside occupational groups. In this way, together they can propose corrective policy action.

Conclusion

The findings of this qualitative study support and extend existing research regarding personal cooling and heat prevention research interventions with vulnerable occupational groups. [21,58,62] Personal cooling gear was well received and utilized by the agricultural workers. Sustainable heat prevention studies and governmental protection strategies for occupational heat stress are urgently needed to reduce the risk of heat-related morbidity and mortality and projected climate change health impacts on outdoor workers. The fact that this is the first cooling intervention conducted in the U.S. with agricultural workers shows the lack of investment in research on heat prevention strategies for a marginalized occupational group that suffers the highest rate of heat-related mortality in the country. The lack of federal heat prevention regulations in the 21st century to protect vulnerable occupational groups who are primarily people of color and immigrants continues the pattern of disregard and denial of the harsh working conditions borne by communities of color and immigrants.[90] Heat-related morbidity and mortality is preventable.

Chapter Five: Summary of Results and Conclusion

This is the first field-based study to pilot cooling intervention among agricultural workers in the US using biomonitoring equipment. This study uses a mixed methods approach that integrated qualitative and quantitative data to yield multi-dimensional and synergistic understanding of the results. Therefore, advancing the knowledge of cooling interventions among vulnerable occupational groups, specifically agricultural workers. This study was guided by the biomonitoring methods used in The Girasoles Study (1R01OH010657-01), the Farmworker Vulnerability to Heat Hazards Framework, a systematic review of cooling interventions, and our community partner— the Farmworkers Association of Florida (FWAF). The specific aims of the study were: 1) Determine the feasibility of utilizing a cooling bandana, a cooling vest, or both a cooling vest and a cooling bandana together; 2) Determine the effect of these interventions on core body temperature and self-reported heat-related illness symptoms; and 3) Determine the interrelationships of environmental temperature (ambient temperature and humidity from local weather networks), and personal vulnerability factors [dehydration (urine specific gravity), physical activity (actigraphy), age, sex, body anthropometrics (body fat, height, weight, waist/hip circumference)], and work characteristics.

The Farmworker Vulnerability to Heat Hazards Framework[37] guided this dissertation study. To help individual workers respond to this heat stress, we focused on improving workers' adaptive capacity (includes includes clothing, hydration, and work hygiene) by using cooling interventions while working and examining their physiological response to heat stress. The scientific premise of this study is supported by our ongoing research and preliminary data from agricultural workers in Florida[11,17,28,29,37-44] and by the other national and international research studies that are documenting the acute and chronic impacts of heat exposure in various agricultural populations. There is limited evidence on cooling interventions for maintaining core body temperature below the recommended physiologic limit (38°C, or 100.4°F) recommended by the American College of Governmental

Industrial Hygienists[34] , which has led to the development to this dissertation study. This pilot study is timely and has set the foundation for identifying evidence-based and culturally appropriate occupational cooling intervention strategies for keeping workers safer while they labor in extreme heat conditions, reducing HRI and heat-related deaths for agricultural workers in Florida and other regions around the U.S.. As such, findings from this pilot study have already informed the design of a large-scale intervention proposal submitted to the National Institute for Occupational Safety and Health (NIOSH).

In April-May of 2018 and 2019 we conducted pilot studies in Homestead and Pierson, Florida, to examine workplace personal cooling gear interventions that could prevent HRI without interfering with daily work routines. Participants were randomized to 1 of 4 groups: 1) no intervention, clothing as usual; 2) cooling bandana; 3) cooling vest; and 4) both the cooling bandana and cooling vest. An important component in selecting the cooling devices to be examined was that the devices allowed free range of motion and unrestricted mobility while the participants worked in agricultural fields. Cooling devices in this pilot include the TechNiche Elite Hybrid Cooling Vest (Vista, CA, Figure 1) which includes cooling inserts and weighs 5 pounds. The Chill-Its® 6700CT Evaporative Cooling Bandana with Cooling Towel (Ergodyne, St. Paul, MN, Figure 2), constructed with polyvinyl acetate (PVA) material, is the second device we examined, which is also reusable, affordable, and easy to use. Biomonitoring equipment worn by the participants included: 1) a CorTemp® Data Recorder (HQInc., Palmetto, Florida) to record core body temperature from the CorTemp® pill sensor; 2) the Polar® T31 heart rate transmitter belt; and 3) an ActiGraph™ GTX3+ (ActiGraph, LLC, Pensacola, Florida) to capture physical activity.

The three manuscripts included in this dissertation describe the findings from the specific aims of this study and a systematic review on cooling interventions with outside occupational groups. **Chapter 2** provides a comprehensive review of the literature on published studies of cooling interventions designed for outdoor workers conducted at either worksites or in simulated climatic chambers. A systematic search of PubMed, Embase, and Web of Science yielded a total of 1014 articles published from 2000 – May 2019. A total of 19 peer-reviewed papers were selected to be part of this review. The studies focused on multiple types of cooling interventions: cooling gear (vest, bandanas, cooling shirts, or head-cooling gel pack), modified work anti-stress uniforms, forearm or lower body immersion in cold water, pouring water on head and hands, ingestion of a crushed ice slush drink, electrolyte liquid hydration, and modified OSHA recommendations of drinking water and resting in the shade. Our study extends existing research regarding personal cooling and heat prevention research interventions with vulnerable occupational groups. [21,58,62]

Chapter 3 discuss the effectiveness of the cooling interventions (Aim 2) and the interrelationships of environmental temperature, personal factors, and work characteristics (Aim 3). A total of 84 workers underwent randomization and 78 participants completed one workday trial. There were 20 participants in the bandana group, 20 in the vest group, and the combination (bandana and vest) group had 21 participants, and the control group had 17 participants. The mean age of the participant was 42 (standard deviation [SD], 9), average years of education was 6 (SD, 3), and the majority were female (66%) from Mexico (79%). Mean body mass index (BMI) was 31 (SD, 7), 18% reported a history of hypertension and 11% reported a medical history of diabetes mellitus type 2. The mean maximum heat index to which participants were exposed ranged from 86°F to 89°F and mean maximum relative humidity was 82% to 84%. Of the 84 workers that enrolled, 35 worked in ferneries, 34 in nurseries, 10 with field crops, and 5 in landscaping. The mean years in agriculture was 17 (SD, 9), and the median workday was 8.2 hours long. This randomized trial showed the bandana was protective against exceeding a core body temperature of 38.0°C compared to the other groups; although, not statistical meaningful due to insufficient power. Nonetheless, we are encouraged with the results of the bandana group, which also had the lowest proportion of workers exceeding a core body temperature of 38.0°C among all groups and nearly 70% did not report any HRI symptoms.

Chapter 4 discusses the feasibility of agricultural workers utilizing cooling interventions (Aim 1). During semi-structured interviews at the post-workday visit, we assessed workers' views on the practicality and effectiveness of the cooling devices. The bandana group had the most positive responses to an intervention. While the vest and the combination group reported some discomfort with the vest, most agreed the cooling vest did help to cool them and was comfortable. These findings are consistent with the results of international studies in various industries with outside workers who reported that cooling bandanas and vests were comfortable and effective.[21,58,62] However, it is important to note that the majority of the studies in our systematic review had scheduled work-rest cycles, which is different to the work conditions of agricultural workers in our study. In our study, the workers wore the bandana and vest while working and without having regularly scheduled rest breaks. The vest was reported by a few workers to be uncomfortable and heavy once it melted, which suggests that using a cooling vest may be better suited to use during rest breaks. However, the challenge for agricultural workers in Florida (as in many parts of the country and the world) is that regularly scheduled rest breaks are not implemented by agribusiness nor government bodies. This keeps workers vulnerable to heat stress.

Clinical Implications

At the individual level, rural and occupational nurses should assess workers' occupational heat prevention practices. Nurses should also provide education on methods to prevent HRI and recognize early signs and symptoms of HRI and on initiating treatment by moving an affected worker to a cool location to rest and ingest electrolytes.[18] At the sector level, occupational health nurses should also work with employers to implement a heat acclimatization plan which provides guidance about the gradual progression of time spent while working in the heat for all new employees.[18] In addition, crew leaders and supervisors should also be trained on recognizing signs and symptoms of heat stroke. They should also learn how to initiate on-site cooling by moving an affected worker to a cool location, beginning cold water immersion, or applying ice on the groin and axillae. Moreover, they should be prepared to call for emergency medical attention.[89] At the national level, nurses have a responsibility to collaborate with public policy officials. For example, nurses should help officials understand the impact of climate change on human health as well as the lack of regulatory protections for outside occupational groups. In this way, together they can propose corrective policy action.

Research Implications

Evidence-based research is also needed on heat stress protection interventions including personal cooling gear, heat stress prevention training, and emergency aid training for heat stroke. Although there have been some cooling interventions studies internationally, to date there are no published field-based cooling interventions with agricultural workers in the U.S. The findings of this qualitative research revealed that personal cooling gear was well received and largely utilized by the workers. Therefore, this demonstrates that intervention field-based research is feasible. An important factor to conduct better field-based research is partnering with the agricultural sector to engage in research at agricultural worksites. Future studies should also include economic evaluations to measure productivity and a cost-benefit analysis to determine if the short and long-term benefits of investing in cooling gear outweigh the cost of implementation.

Limitations

Methodological limitations should be taken into consideration when interpreting the results of this pilot study. First, this study had a small sample size that was further decreased in size during the analysis phase due primarily to loss of core temperature files to technical issues. The control group also had fewer participants due to workers withdrawing from the study. A convenience sample of agricultural workers in central and south Florida were randomly assigned into the intervention groups or control group, which may restrict the external validity of this study. Although the randomization was thought to be successful in creating the intervention and control groups with similar baseline characteristics, the vest and combination group had higher physical activity compared to the bandana and control group over the course of the workday, which was likely due to chance. However, its impact on the internal validity of the findings is likely to be limited because, based on logistic regression analysis, the results revealed that physical activity had no significant effect on exceeding a core body temperature of 38.0°C (Table 7). Despite limitations, this pilot study has an important strength which is that it was conducted in real work conditions with agricultural workers during one full workday.

Conclusion

This study found that agricultural workers that used a bandana while working in a hot environment has the potential to be protective against exceeding a core body temperature of 38.0°C. Comprehensive empirical study on a large-scale are needed to determine if using a cooling bandana and other cooling interventions improve long-term health outcomes and work performance, have a potential cost-savings factor, and reduce the risk of heat-related morbidity and mortality. If cooling interventions are shown to be feasible and effective across diverse outside occupational groups, this innovative intervention could improve working conditions for vulnerable occupational groups at risk of increased ambient temperature due to climate change, such as agricultural workers, and improve their health outcomes. Heat-related morbidity and mortality is preventable, and vulnerable occupational groups merit protection.

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