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Characterizing Heat-Related Illness in Florida Farmworkers: A Feasibility Study

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Doctor of Philosophy

Nursing

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Abstract

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Background: With increasing trends of rising temperatures and extreme weather events, agricultural worker populations are at an increased risk for heat-related illness (HRI). A few studies utilizing survey methods have examined the predictive factors of HRI development in farmworker populations, but studies to examine the feasibility of field-based biomonitoring of heat-related illness in farmworker populations are needed.

Purpose: The purpose of this dissertation was to develop a guiding framework conceptualizing farmworker vulnerability to heat, assess the feasibility of field-based biomonitoring of HRI in a sample of farmworkers and characterize the heat stress response.

Sample and Design: This was a feasibility study utilizing a repeated measures design guided by the Farmworker Vulnerability to Heat Hazards Framework. Forty-three male and female fernery workers participated in a biomonitoring protocol over 3 workdays following an initial baseline visit. The biomonitoring protocol included continuous core temperature, heart rate, actigraphy monitoring over the course of the workday as well as dehydration assessment before and after the workday. Self-reported HRI symptoms were also recorded, along with body composition measurements. Analyses included means, descriptive plots, and a logistic regression utilizing a generalized estimating equations approach to predict the key outcome variable of whether a participant's body core temperature (T_c) exceeded 38.0ºC (100.4ºF).

Results: Core temperature data was captured for two study days in nearly 90% of study participants**.** An improved protocol for core temperature monitoring was developed and best methods for future studies were identified. Participant T_c exceeded 38.0ºC on forty-nine (57%) of the workdays examined (n=86). On average, for those who met or exceeded 38.0ºC (100.4ºF), the duration of time was 79 minutes (SD=73, range=255). Energy expenditure was found to be a significant predictor (OR=1.08 [1.005,1.15]) for the key outcome variable and once adjusting for energy expenditure being female was also a significant predictor (OR=5.37, $CI_{.95}$[1.03,18.30]).

Conclusion: The Farmworker Vulnerability to Heat Hazards Framework provides a base for designing studies regarding HRI in farmworkers. Field-based biomonitoring is indeed feasible and findings should be utilized to guide the design and implementation of future studies.

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In solidarity.

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INTRODUCTION

Statement of the Problem

With nine out of the ten hottest years on record occurring in the last decade, excessive heat is increasingly becoming a global public health priority. Mounting scientific evidence has documented the adverse health impacts of global warming, gaining the attention of public health organizations across the globe. Average air temperatures are projected to increase by 0.1°C per decade over the next two decades (1). This is of critical importance because with every degree Centigrade increase, mortality rates related to heat rise by 2-5% (2). The increasing severity of heat waves will lead to excess heat-related morbidity and mortality (1).

Although a baseline temperature shift would affect all populations, vulnerable populations most adversely affected will include the elderly, the poor, and individuals who work outdoors including agricultural workers, construction workers, military personnel and firefighters (3). Farmworkers face a risk of heat-related death that is more than 20 times the risk faced by other worker groups (4).

The Occupational Safety and Health Administration (OSHA) is the federal agency charged with educating farmworkers and their employers about heat hazards, management of these hazards, and early recognition of symptoms. Currently, no federal heat hazard regulations exist for preventing heat-related illness (HRI) in farmworkers, despite disparities in heat-related mortality when compared to non-farmworkers (5). Under the OSHA Act, employers have a duty to protect workers from recognized serious hazards in the workplace, including heat-related hazards. OSHA has issued general recommendations for the protection of workers in all hot work environments, primarily **water, rest, shade**. The modification of the work environments by the farmworkers themselves is often limited and there may be a lack of availability of shade, inadequate access to water while working in the fields and irregular work break schedules for workers who are paid based upon how much crop they pick, providing little incentive for workers to take regular rest breaks (6-8). These occupational situations place this population at increased risk for HRI.

Purpose

The purpose of this study is to assess the feasibility of field-based biomonitoring of heat-related illness in farmworkers, characterize the work environment of farmworkers, while also exploring the relationship between individual physiologic responses to heat stress and personal characteristics. By establishing an approach to field-based biomonitoring of HRI, and exploring factors relevant to heat stress outcomes, this work will guide the implementation of larger studies to examine HRI in farmworker populations. The knowledge gained from these future studies will then inform the piloting of interventions to decrease the risk of developing heat-related illness in these vulnerable farmworker populations.

Specific Aims

Aim 1. Assess the feasibility of field-based biomonitoring of heat stress in Florida farmworkers

Objective 1. Determine participant acceptability for occupational, field-based methods.

Objective 2. Determine feasibility for the physiologic assessment of heat stress response.

Objective 3. Compare dehydration assessment methods.

Objective 4. Compare body composition assessment methods.

Aim 2. Characterize occupational heat exposure and key vulnerability factors in Florida farmworkers.

Objective 1. Quantify the level of occupational heat exposure.

Objective 2. Quantify the level of workplace exertion.

Objective 3. Describe the variability in hydration status, body composition, gender, and age.

Aim 3. Characterize heat stress response in Florida farmworkers

Objective 1. Calculate the prevalence of heat-related illness symptoms.

Objective 2. Quantify the amount of time workers sustained temperatures above the heat stress risk threshold (100.4ºF).

Objective 3. Examine worker variability in buffering physiologic heat stress response via the Physiologic Strain Index.

Objective 4. Examine the influence of occupational heat exposure and key vulnerability factors on the development of HRI.

Paper 1: Farmworker Vulnerability to Heat Hazards: A Conceptual Framework

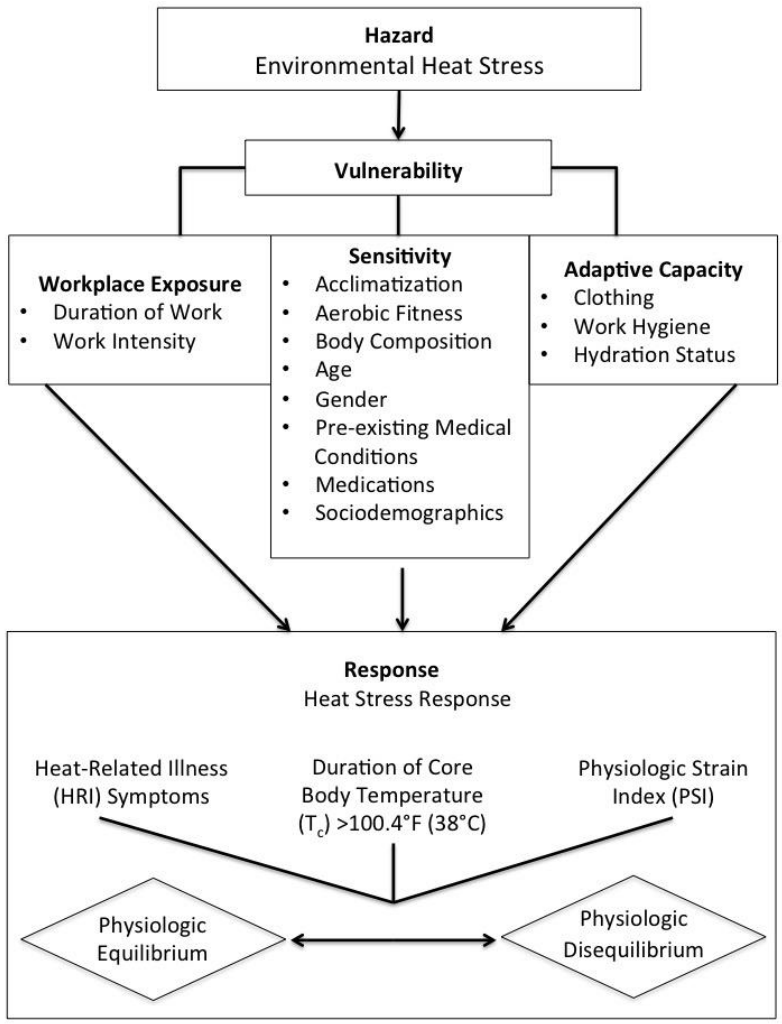
Paper 2: Heat Exposure in Central Florida Fernery Workers: Results of a Feasibility Study

Paper 3: Elevated Core Temperature in Florida Fernery Workers: Results of a Pilot Study

Conceptual Framework

The Farmworker Vulnerability to Heat Hazards Framework (Figure 1) was developed to guide the design of this study and is included in this dissertation as Paper 1 entitled Farmworker Vulnerability to Heat Hazards: A Conceptual Framework (9). This framework was inspired by Romero-Lankao and Qin's framework entitled "A conceptual framework of urban vulnerability to global climate and environmental change" (10, fig1) and Ionescu, Klein, Hinkel, Kumar and Klein's "Graphical representation of the conceptualization of vulnerability to climate change in the IPCC Third Assessment Report" (11, fig1) which was based upon the ideas for conceptualizing the vulnerability of communities and systems to climate change by the Working Group II of the Third Assessment Report of the Intergovernmental Panel on Climate Change (12). The Farmworker Vulnerability to Heat Hazards Framework, inspired by previous frameworks and ideas (10-12), conceptualizes the hazard (environmental heat stress), the vulnerability factors of workplace exposure, sensitivity and adaptive capacity, and finally, a heat stress response that results in physiologic equilibrium or disequilibrium in these workers.

Figure 1. Farmworker Vulnerability to Heat Hazards Framework



Relevance of the Study

Now and in the future, global warming will continue to be a persistent public health threat affecting all living spaces, including those where we live and work. Escalating trends in global warming place vulnerable agricultural populations at increased risk for heat-related illness (HRI) (13). HRI occurs when the body's innate compensatory mechanisms for combating heat stress, including evaporative cooling, are overburdened. Agricultural workers are highly susceptible to heat stress, given routine occupational exposure to hot, humid environments.

Several decades of research have examined physiologic response to non-fatal heat strain in the public (14, 15), athletes (16), firefighters (17) and military personnel (18-20). Despite the history of research centered on other groups, heat stress remains an understudied, but important occupational hazard for agricultural workers (8).

Research exploring the relationship between personal physiologic factors and outdoor work in agricultural settings has the potential to advance the state of the science for climate adaptation, specifically, individual heat stress response in various occupational conditions. At the same time, this research provides important insights into the development of targeted heat-prevention interventions that may be applied to other vulnerable subgroups including the elderly and chronically ill. More research is warranted to characterize and quantify the extent of heat as an occupational hazard to inform public health interventions that protect vulnerable populations.

Defining Heat-Related Illness

Heat stress occurs when environmental and individual factors increase core body temperature to the point where the body's capacity to maintain equilibrium is exceeded, leading to HRI (21). Environmental sources of heat stress include high ambient air temperature, high humidity and low airflow, while individual sources of heat stress include metabolic heat from muscle exertion (20, 22). If heat-related symptoms go untreated, a heat-related illness cascade may occur, ranging from heat rash, heat syncope, heat cramps, to heat edema, heat exhaustion, heat stroke, and in severe cases, heat-related death (23, 24). When cooling is applied in clinical practice as a treatment for HRI, including heat stroke, the goal is to reduce the core temperature to below 100.4°F (23).

Water stores in the body are utilized resulting in the production, distribution and release of sweat on the epidermis. Perspiration is promoted to water vapor in response to the external temperature gradient to provide evaporative cooling. If evaporative cooling is disrupted due to excessive humidity in the environment or impermeable clothing, fluid accumulates on the skin resulting in fluid loss, potential electrolyte imbalance and a rise in body core temperature (23, 25, 26).

Pre-existing chronic conditions such as diabetes, kidney disorders and cardiac arrhythmias as well as certain medications can increase an individual's vulnerability to heat stress (23, 27, 28). The inflammatory and metabolic processes underlying HRI can place excess stress on multiple organs including the heart, lungs and kidneys, potentiating co-morbid chronic conditions and further compounding the health burdens of already vulnerable populations. In some cases heat exposure can precipitate neurological symptoms; workers may become disoriented and unaware of progression of their illness along the heat-related illness cascade, potentiating further health decline and work related-injuries (23).

For this research *heat stress* refers to the environmental thermic force exerted as well as the individual (metabolic) thermic force exerted on a person (29). Sources of individual heat stress are borne of internal metabolic processes during rest and physical exertion and can be moderated by clothing (29). In the Farmworker Vulnerability to Heat Hazards Framework which guides the current work (9), external sources of heat stress comprise the heat hazard component. Metabolic thermic force is generated based upon work intensity, and couples well with the duration of time working to yield the component of workplace exposure, which will vary between individuals. *Heat-related illness* refers to the spectrum of conditions, symptoms and precursors of diagnoses under the National Center for Health Statistics' (2010) International Classification of Diseases and Injury (ICD-10) "Effects of Heat and Light".

Fernery Operations

Fernery workers are a subset of farmworkers who grow and harvest ornamental ferns in a high heat environment. Estimates provided by local farmworker community organizations indicate over 10,000 fernery workers reside in Central Florida (7). Beyond exposure to high heat environments and comparable workloads encountered by workers in other agricultural settings, the work in ferneries is performed in low airflow, enclosed environments under large shade cloths, with high temperatures, high humidity, and poor ventilation. Additionally, this vulnerable agricultural subpopulation uses self-provided low-cost impermeable clothing (e.g., plastic trash bags tied around the farmworker's torso) to protect themselves from pesticide exposure arising from close contact with the harvested plants (8). The workplace demand for productivity (i.e., daily pay is based on number of harvested ferns) pushes fernery workers beyond safe physical exertion levels compromising the body's natural compensatory mechanisms for dissipating heat. In turn, uncompensable heat stress creates a dire situation for these workers that has the potential to lead to heat-related morbidity (26).

Heat-Related Illness in Farmworkers

If left untreated, HRI can lead to losses in productivity, disability, exacerbation of chronic illnesses and in severe cases, death (30). Fortunately, HRI is both preventable and treatable when identified early (23). It is estimated that there are 300,000 individuals working in various agricultural settings in Florida (31). There is a paucity of research characterizing the hazardous work environment for this vulnerable agricultural population. To date, almost no studies have documented the physiologic factors that lead to the increased heat-related morbidity and mortality observed among farmworkers. Even fewer studies have results verified by physiologic data.

Mirabelli et al. (32) conducted a cross-sectional survey of 300 farmworkers in North Carolina and found that having worked in extreme heat was reported by 94% of the farmworkers and that 40% of those workers reported having experienced HRI symptoms, including hot, dry skin, confusion, dizziness, fainting, muscle cramps and nausea or vomiting. Fleischer et al. (33) performed a cross-sectional survey of 405 farmworkers in Georgia. Thirty-four percent of workers responded they had experienced three or more heat-related symptoms during the previous week. When asked about potential barriers to the prevention of heat-related illness at work, over two-thirds of respondents reported a lack of training, and no access to regular breaks, shade or medical attention.

Another recent study cross-sectional study (34) in a group of farmworkers in Washington (n=97) examined risk factors for the development of the HRI symptoms of dizziness/light-headedness or heavy sweating and found that fewer years in working in agriculture, being younger, pay by the piece rather than an hourly wage and having to travel farther to the toileting facilities (greater than a 3-minute walk) were associated with an increased odds of development for HRI symptoms. A study of Oregon farmworkers (35) examined self-reported HRI symptoms including the level of concern for developing HRI, heat knowledge and worksite factors. The authors found that 30% of workers reported experiencing 2 or more HRI symptoms in the last week at work. Workers with higher score for heat knowledge were more likely to report feeling comfortable taking breaks and workers paid by the piece or those who had faced HRI previously were more likely to report being “very concerned” about HRI.

In California, the MICASA study (36), a large survey-based study of 467 hired farmworker households, examined HRI knowledge and practices. It was found that 91% of respondents reporting having received HRI training, but that heat-related knowledge was moderate and gaps in knowledge regarding acclimatization was low. Gender differences were found in levels of concern regarding heat illness with women reporting higher levels of concern as compared to male respondents, however, males scored higher on heat-related knowledge prompting the authors to suggest gender-specific approaches in HRI prevention training. A few studies have begun to characterize the heat hazards facing farmworkers at worksites. Marucci et al. (37) assessed the heat stress of workers employed in vegetable grafting operations in Mediterranean greenhouses. Physiological biomonitoring was not performed. The primary indices used for heat stress risk in this work environment were the wet bulb globe temperature (WBGT), and two microclimatic indices required by safety regulations, Predicted Mean Vote (PMV) and the percentage of thermally dissatisfied people (PPD). PMV and PPD account for factors including metabolic rate, clothing factors, self-reported comfort and various climatic components (EN ISO 7730:2006). Marucci et al. (37) concluded that the greenhouse workers were at a significant risk for heat stress from April through October (the workers have a break during the months of July and August), despite the use of shade cloths on days that the ambient temperature exceeded 77°F. Crowe et al. (38) conducted an observational study of 42 sugar cane workers in Costa Rica during the non-harvest season. Metabolic rates of workers were estimated using weight and height only and physiologic monitoring was not performed. WBGT collected by local meteorology stations was measured and metabolic rates were calculated for workers by measuring height and weight, and observing worker movements and clothing. The results of their heat stress models indicated that workers should only be allowed to work for 15-24 minutes out of every hour. The authors stated that the results of their study underscored the importance of intervening in tropical climates to preserve worker productivity on health, rather than only crop production and pest control, before conditions worsen.

Another study has assessed heat conditions in farmworker housing. Quandt et al. (39) reported on the heat index present in common and sleeping rooms in the housing of 170 North Carolina farmworkers. They reported they workers are receiving little respite from the heat at home, with dangerous heat indices in most rooms, even with the use of air conditioning. The authors suggest that the temperatures experienced in the evening and at night could affect an individual's ability to recover from the heat stress experienced during the workday, since physiologic adaptations to continuous high heat exposure during sleep do not occur and high ambient temperature and humidity can affect the quality of sleep (40-42). These findings further potentiate the heat hazards faced by this vulnerable occupational group.

There are only two published reports, to date, that explore the biomonitoring of agricultural workers. The first is a study of seasonal agricultural workers 15 to 20 years of age that examined self-monitoring of heart rate, sublingual temperature and sweating to quantify heat strain (43). Sublingual temperature was measured before and after each shift, heart rate monitoring occurred throughout the workday using a wrist heart rate monitor, and wet bulb globe temperature (WBGT) measurements were recorded for the worksite conditions. The authors found that heart rate was the first physiologic response to surpass their proposed thresholds, ahead of sweating and sublingual temperature in response to heat stress. This study relied on heart rate as the continuously monitored heat stress response variable, and did not include continuous monitoring of body core temperature. The second study, by Cecchini et al. (2010) (44), examined a small sample (n=5) of greenhouse and field workers during harvest. These authors utilized the Predicted Heat Strain (PHS) model, which estimates a predicted thermal load based upon rectal temperature, water loss, exposure time, metabolic expenditure, and thermodynamic measures (44). The authors found that none of the workers' core temperatures exceeded 37.6°C (99.68°F), which was below the calculated thermal overload reference, and only one of the five workers experienced water loss over the recommended limit. This study was limited by its small sample size, a short study period, and lack of continuous temperature and cardiac monitoring.

Common methodological and design issues encountered in field studies attempting to document hazards in agricultural work include barriers to farmworker recruitment due to the migratory nature of their work, the identification of appropriate access channels for targeted recruitment, enumeration of this population, perceived fear of confidentiality breeches resulting in employer knowledge of worker participation in the research study, and the difficulty of continuous on-site occupational hazard assessment. While some farm owners and operators are willing to cooperate with researchers in supporting investigations, the exclusive use of these "worker-friendly" sites may block the inclusion of those who are most vulnerable and subsequently lead to biased findings portraying an overly optimistic reality for these workers.

In summary, while multiple studies have described the vulnerability of agricultural workers to the effects of heat exposure, there is a compelling need for further evidence from large worksite-based studies that combine continuous biomonitoring of body core temperature and heart rate monitoring, combined with the assessment of occupational environmental, and personal characteristics that contribute to this vulnerability. Such creative, comprehensive and tested study designs are needed to lay the foundation for other large, worksite-based studies

Vulnerability of Farmworkers

Farmworkers face institutional, legal, social, health, economic and cultural vulnerabilities. Institutionally, farmworkers are exceptionally vulnerable since they are in the position in which their employer governs their livelihood. The working conditions are dangerous and the farmworkers are not compensated with hazard pay, overtime, minimum wage or protections afforded workers in other professions (45). In the power relationship of the farmer and the farmworker, no matter how harsh the working conditions or the living conditions provided as part of the employment, the farmworker cannot raise complaints or report abuse out of fear of job loss (46, 47). Farmworkers experience a variety of occupational exposures at work, including chemical exposures from pesticides, heat stress exposure and ergonomic hazards from repetitive motions (8, 48). Oftentimes these workers are migratory and living without their immediate family members, leading to economic hardship because they are supporting a household from afar (49, 50). Additionally, they may face emotional strain from their separation from family.

Instead of an hourly wage, farmworkers are often paid a “piece rate”, potentially imparting additional economic hardship along with physiologic hazards because workers often push themselves beyond their physical limits in order to work toward a minimal living wage (8). Farmworkers are often subjected to adverse working conditions over which they have little control and where they do not have ready access to water and rest breaks. The power gradient between farmers and farmworkers may also influence workers’ recourse related to unsafe working conditions. Additionally, the prevalence of chronic health conditions such as diabetes mellitus II, renal disease, cerebrovascular disease, respiratory diseases and heart disease in farmworkers is like other working groups, and these conditions may be exacerbated by excessive heat (28, 51, 52). Their vulnerability is also increased by reduced access to health care services afforded to other non-minority groups (53, 54). Currently, no federal heat hazard regulations exist for preventing HRI in agricultural workers, despite disparities in heat-related mortality when compared to non-agricultural workers (52).

Summary

Findings from this project will fill a major gap in the literature by providing baseline data regarding the extent of heat-related illness in this vulnerable group. The goals of this study are to: (1) Assess the feasibility of conducting sophisticated field-based biomonitoring of heat stress in Florida Farmworkers (2) Characterize occupational heat exposure and key vulnerability factors in Florida; and (3) Characterize the physiologic heat stress response of farmworkers in Florida. This living laboratory for heat-related illness, in an uncontrolled occupational environment, provides novel and original field data regarding the extent of HRI and the HRI-related factors for individuals. This work will provide baseline information about the feasibility of this type of hazard assessment in farmworkers, paving the way for future studies, and provide critical, biomonitoring information regarding the heat-related hazards of agricultural work.

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PAPER 1

Farmworker Vulnerability to Heat Hazards: A Conceptual Framework

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Abstract

A framework was developed to conceptualize the potential factors related to the development of heat-related illness in farmworkers and identify measures for characterizing these factors. The objective of this framework was to conceptualize the components surrounding farmworker vulnerabilities to occupational heat conditions and describe how these components lead to a physiologic response. Components of this framework include the hazard, vulnerability factors and the heat stress response. Vulnerability factors include workplace exposure, sensitivity and adaptive capacity. The summation of the vulnerability factors of workplace exposure, sensitivity and adaptive capacity determines a worker's heat stress response. A worker's heat stress response can be classified as progressing towards two outcomes: physiologic equilibrium or physiologic disequilibrium. This framework sets an initial starting point for the design and development of studies of HRI in farmworker populations.

Introduction

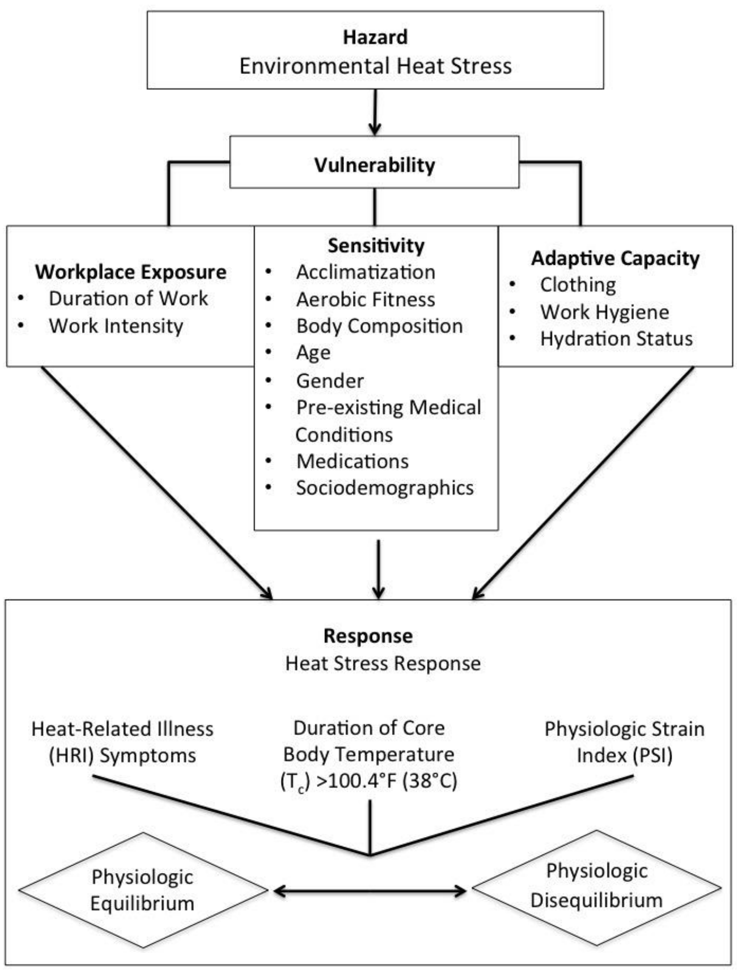
Now and in the future, global warming will continue to be a persistent public health threat affecting all living spaces, including those where we live and work. Escalating trends in global warming place vulnerable agricultural populations at increased risk for heat-related illness (HRI) (7). HRI occurs when the body's innate compensatory mechanisms for combating heat stress, including evaporative cooling, are overburdened. Agricultural workers are highly susceptible to heat stress, given routine occupational exposure to hot, humid environments.

Several decades of research have examined physiologic responses to non-fatal heat strain in the public (9, 10), athletes (12), firefighters (13) and military personnel (14-16). Despite the history of research centered on other groups, heat stress remains an understudied, but important occupational hazard for agricultural workers (17). Recently work has begun to characterize heat-related illness in farmworkers utilizing survey methods (18-21), a longitudinal database of visit records from Community and Migrant Health Centres (C/MHCs) (22, 23) as well as field-based continuous biomonitoring (24, 25). Research exploring the relationship between personal physiologic factors and outdoor work in agricultural settings has the potential to advance the state of the science for climate adaptation, specifically, human physiologic responses to environmental heat. Given the complexity of the response of the human body to the exogenous factor of increasing environmental heat, models are needed to promote our understanding of the vulnerability and physiologic response and to serve as a guide for research, policy and action in this vital area of public health.

Framework Components

A framework describing the factors surrounding heat stress in farmworkers needs to conceptualize the physiologic processes occurring internally via the body's attempt to maintain equilibrium in relation to heat stress sources and moderating factors. Romero-Lankao and Qin have proposed a framework entitled "A conceptual framework of urban vulnerability to global climate and environmental change" (26, fig1) outlining factors related to the vulnerability of urban environments to climate change. The tenets of their framework include the hazard, exposure, sensitivity, adaptive capacity and response, which were first developed to explain the vulnerability of systems to climate change in a framework entitled "Graphical representation of the conceptualization of vulnerability to climate change in the IPCC Third Assessment Report" (27, fig1) developed by Ionescu, Klein, Hinkel, Kumar and Klein that was sourced from the ideas surrounding climate change vulnerability from the Working Group II of the Third Assessment Report of the Intergovernmental Panel on

Figure 2. Farmworker Vulnerability to Heat Hazards Framework



Climate Change (28). In their framework, Romero-Lankao and Qin present vulnerability in the context of climate change resilience of cities as resulting from a dynamic interaction between the hazard, vulnerability factors of exposure, sensitivity and adaptive capacity rather than simply a propensity to be harmed based solely upon the magnitude of the oncoming hazard (26, 27, 29). These frameworks (26, 27, 29) inspire the translation of these ideas into a framework that can

Key Definitions

Heat-related Illness (HRI) Symptoms – The clinical manifestations of heat-related illness that occur along a cascade from mild to critical that may include excessive sweating, cramps, headache, edema, fatigue, dizziness, fainting, nausea and vomiting (1-3).

Core body temperature (Tc) – The dynamic temperature of the vital organs in the body considered to be most accurate in the pulmonary artery (5), but most accurately measured in field-based settings via the gastrointestinal tract (6).

Physiological Strain Index (PSI) – The degree that the body is unable to maintain core temperature prescribed by the hypothalamus described on a universal scale of 0–10 based upon heart rate and rectal temperature (T_{re}) (11).

capture the dynamic circumstances surroundings an individual's physiologic response to heat stress (Figure 1).

Wet-bulb globe temperature (WBGT), comprised of natural wet bulb temperature (T_{nwb}), dry-bulb temperature (T_{db}), and black globe temperature (T_{bg}), is a primary index that describes heat stress in a given environment, which in this framework serves as a measurement of the hazard (30). WBGT can be measured in indoor environments and confined spaces as well in outdoor environments. Ideally, microclimate WBGT measurements would be acquired at the worksite using standardized instrumentation and calibrated temperature equipment, but in lieu of on-site monitoring, estimating WBGT from local meteorological data is an option due to the wide accessibility of these readings by the local or regional weather services (31, 32). With WBGT estimations, outdoor workers can be advised of acceptable work and rest cycles according to the level of environmental heat stress and the level of individual workload (light, moderate or heavy), defined by the number of watts (W) expended per hour (33). For example, when the WBGT reaches 29ºC, a worker engaging in a moderate workload, classified as an energy expenditure of 235-360 watts per hour (W/hr), he or she should spend 25% of every hour in recovery in an effort to decrease the risk of developing HRI (33). If agricultural workers are employed in operations where portions of the work take place inside partially enclosed, non-temperature controlled areas like packing houses, greenhouses, or inside packing and loading trailers, WBGT from meteorological data may underestimate the actual conditions. In these cases, direct WBGT at the worksite would be preferred, to more accurately measure the level of environmental heat stress to guide the choice of the appropriate work-rest cycle.

Although, WBGT is the standard occupational environment temperature assessment, the National Weather Service calculates the Heat Index (34, 35) from meteorological data, specifically relative humidity (RH) and ambient temperature (T_a), to guide the issuance of heat warnings for communities that stratify the risk of heat-related illness (36) and is a possible alternative to WBGT for capturing the degree of heat hazard.

The state of California has instated Heat Illness Prevention Regulations (CCR, section 8 §3395. Heat Illness Prevention) based upon guidance from the Occupational Health and Safety Administration (OSHA) to protect farmworkers. These regulations mandate employers to be aware of daily ambient temperatures and to follow situation-based recommendations based upon these readings on a given day. Specific actions include the provision of shade when ambient temperatures reach 80ºF and mandatory rest breaks of 10 minutes in length every two hours when the environmental temperature exceeds 95ºC. Community and regionally-based weather monitoring can provide accurate and accessible information from which public health surveillance and situation-based recommendations can be developed in other regions of the country.

As stated above, an individual's vulnerability is determined by three factors: workplace exposure, sensitivity, and adaptive capacity (26, 27, 29). Workplace exposure quantitatively relates to the extent to which an individual (i.e., agricultural worker) experiences a hazard (environmental heat stress). For instance, of importance is the nature of the work that the individual is engaged in, the duration of the work, and the physical demands involved. Farmworkers may work long hours (17) and agricultural work is among the most demanding of all occupational classes (37). In the Farmworker Vulnerability to Heat Hazards Framework, workplace exposure is the measure of the duration of work and the intensity of work. Of note is that there are two sources of heat stress including environmental heat stress (the hazard) and internal heat stress, which is born of one's own metabolic processes. For this framework, internal heat stress is captured under workplace exposure because its magnitude is entirely dependent upon the amount of time working and the intensity of work. Environmental heat stress (the hazard) exists independently of workplace exposure, and the dose of the hazard is titrated by the degree of workplace exposure, which is why workplace exposure is a component of vulnerability in this framework.

The second component of vulnerability is sensitivity. Sensitivity consists of modifying factors that can have a positive or negative impact on an individual's vulnerability to heat hazards. In the context of this framework, sensitivity includes factors of acclimatization (10, 38), aerobic fitness (39), body composition (40, 41), age (42), gender (43), pre-existing medical conditions and certain medications (2, 44-46), as well as other sociodemographic factors such as housing (47).

Key Definitions

Aerobic Fitness – The level to which an individual can perform physically at a high level for an extended period of time which is dependent upon the degree of efficiency that the cardio-respiratory system can oxygenate the blood, transport that oxygenated blood to the muscles being used, and how efficiently the involved muscle cells can uptake and utilize that oxygen to create an output of power (4).

Acclimatization – The process by which an individual undergoes physiologic adaptations to improve their ability to withstand strain placed on the body by heat stress, including a decrease in heart rate, perceived exertion, increased plasma volume and decreased core temperature (8).

Adaptive capacity refers to the ability of a worker to utilize resources to counteract heat stress and is the primary modifiable component of vulnerability; however, some of these components may vary including workplace hygiene (e.g. availability of water and toileting facilities, and ability to take regular breaks) (17, 19, 48). Heat-related illness prevention knowledge and practices, including the training of crew leaders and supervisors in HRI prevention and early action algorithms, could also be included under the adaptive capacity component as aspects related to workplace hygiene.

Further research regarding heat stress experienced by agricultural workers will further illuminate components of sensitivity and adaptive capacity. Recent work examining grower-provided farmworker housing in North Carolina showed that these workers are facing high levels of heat and humidity even after leaving the worksite, during sleeping hours (47). Quandt et al. (47) cite the known detrimental impact of elevated heat and humidity in sleep environments on wakefulness, rapid-eye-movement sleep and slow-wave sleep via a higher thermal load that inhibits the normal decreases in body temperature during sleep (49). This suggests that these workers are at risk for impaired cooling and recovery at night, which could potentially impact an individual's response to heat at the worksite. Further research characterizing the physiologic impacts of the documented high heat indices and high humidity in grower-provided farmworker housing can elucidate the predicted health effects.

The synergy between workplace exposure, sensitivity and adaptive capacity determine an individual's degree of vulnerability by mediating an individual's adaptation to the hazard (heat stress response). If the summation of workplace exposure and sensitivity exceeds an individual's adaptive capacity, then the heat stress response is in disequilibrium, leading to heat-related illness. If an individual's adaptive capacity is high enough to offset their summation of sensitivity and exposure to the hazard, then the heat stress response that is compensatory, leads to physiologic equilibrium. In theory, vulnerability and adaptation can be fluid, with individuals oscillating between degrees of vulnerability related to changing adaptive capacity, workplace exposure or sensitivity resulting in an oscillation between physiologic equilibrium and disequilibrium during the growing season or a single workday.

An individual's heat stress response can be quantified using three metrics: (1) body core body temperature; (2) the Physiological Strain Index (PSI); and (3) heat-related illness symptoms. The American Conference of Governmental Industrial Hygienists (ACGIH) has set a threshold limit value (TLV) for core body temperature a 38°C (100.4°F), which means that workers of unknown medical fitness for their specific work task are recommended to cease work when their core body temperature exceeds this cap to avoid adverse effects from repeated or extended exposure, and if there are multiple workers exceeding the recommended threshold, this indicates the need for workplaces to take steps to attenuate heat exposure (33). These recommendations are made to curtail heat-related illness and injury in worker populations facing high heat exposure. In 2016, the Occupational Health and Safety Administration revised its National Institute for Occupational Safety and Health (NIOSH) Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments (36) and this document supports the use of the TLVs set by the American Conference of Governmental Industrial Hygienists (ACGIH). These criteria also state that there may be exceptions to the 38°C (100.4°F) TLV, in which some workers may be safe to work as long as their core temperature does not exceed 38.5°C (101.3°F) but that these individuals must be medically cleared, remain under medical supervision, are acclimatized, directly supervised, and adequately hydrated (36).

The Physiological Strain Index (PSI) utilizes simultaneous measurements of heart rate and body core temperature to quantify heat strain experienced by an individual and provides a scaled value between 0 and 10, with a value of 10 indicating a physiologic state that is very strenuous (11). It's inclusion as a component of an individual's heat stress response provides a more robust picture of what is occurring physiologically by capturing the cardiovascular and thermoregulatory response to heat stress (11). Lastly, the heat stress response includes the actual heat-related illness (HRI) symptoms experienced by an individual which improves the characterization of the heat stress response beyond physiologic measurements of heart rate and body core temperature. HRI symptoms may not be tied to a specific body core temperature and capturing these symptoms at earlier stages of the heat stress response can aid in the prevention of HRI progression (1, 2, 45).

Conceptual Framework Exemplars

Exemplar 1: Physiologic Equilibrium

A 28-year-old healthy farmworker with no chronic conditions who has been working in the tomato field since 6:30 AM is wearing a long sleeve white t-shirt and notices that she is beginning to feel disoriented and dizzy, indicating a shift towards physiologic disequilibrium in her heat stress response. It is a clear day in June with a WBGT of 28ºC, and she has a moderate energy expenditure. She notifies her crew leader who sends the affected worker for a 20-minute rest and water break, accompanied by another worker, this worker's designated "buddy". During this break, the affected farmworker sits down under the shade of a canopy cloth, refills her water bottle with cool water and adds an electrolyte replacement pill to her water. She also wets a bandana with cool water to place around her neck while resting. The other worker that accompanied the affected worker keeps talking to her throughout her rest break, asking how she is feeling. At the end of the break, the worker is feeling better, the dizziness and disorientation has subsided and the worker walks back with the accompanying buddy worker to the tomato row where the crew is now working and resumes picking.

In this example, the worker was young and did not have any chronic conditions that could have increased her sensitivity. Fortunately, she was also wearing single-layered, light colored clothing and sought out water and an electrolytes supplementation, all of which bolster adaptive capacity. By taking a break she was able to temporarily decrease her work intensity resulting in a temporary decrease in her work intensity. The combination of these factors related to the actions she took to slow the heat-related illness cascade, her personal characteristics and clothing choices resulted in a decrease in her vulnerability allowing her heat stress response to shift back towards equilibrium.

Exemplar 2: Physiologic Disequilibrium

In contrast to the previous example, the following example is an exemplar of a worker experiencing physiologic disequilibrium. In this scenario, a 36-year-old farmworker is picking watermelons in the month of June in Immokalee, FL and loading them into the truck as he and the other crew members follow the loading truck down the row. He is new to this particular crew and crop even though he has worked in agriculture for decades, but has been out of work for the last month. Six hours into the workday he is keeping up with the pace of the loading truck and is feeling fine overall except for some muscle cramps that he attributes to not being accustomed to lifting the watermelons and a headache that he believes is from not sleeping well the night before. He has been drinking water that is stored on the loading truck when the crew stops for breaks decided upon by the crew leader. The WBGT is 29ºC, but the crew leader is unaware of the environmental heat readings and bases the break schedule on the schedule he has always used, despite the current heat wave. Towards the last hour of work, the worker begins to feel nauseated and lightheaded, but knows that the day is almost over and doesn't want to stop early because he is new to the crew and doesn't want to lose productivity.

When the workday ends, he is feeling so nauseated that he doesn't want to drink much water, and he doesn't have a sports drink or a low-sugar electrolyte beverage to drink. Because he is new to the crew, he doesn't have a co-worker that knows him or what he looks like when he isn't feeling well. He walks back to the bus that was the mode of transportation for all the crews to the fields that morning and will be the sole option for the 30-minute ride back to the parking lot at the town center. Pulling himself onto the bus, he steadies himself placing his hands on the top of the seats at each row, as he walks down the aisle towards the middle of the bus where there are some empty seats. He sits down in a seat by himself, hoping that the dizziness will subside if he just closes his eyes. One of the other workers on the bus asks him if he is alright, and he replies that he is feeling dizzy and just needs to close his eyes for a few minutes on the drive back next to the open window. When the bus arrives at the town center, the workers begin to unload off the bus, but he doesn't get up. One of the other workers from the back of the bus notices him and tries to wake him up, but he is unresponsive. Then 911 is called and the other worker stays with him until the ambulance arrives.

For this worker, he started the day in working with new work tasks (a new crop) that he had not previously performed and felt the pressure of being on a new crew, eager to perform well. These circumstances set the stage for increased vulnerability to HRI due to his increased sensitivity from not being acclimatized to the current work environment, and his increased workplace exposure from overexertion related to increased performance pressures as a new crew member. He began to decompensate early in the day when he experienced HRI symptoms of muscle cramps and headache arose, but not identifying these as symptoms of HRI marked his progression down the HRI cascade. His HRI symptoms get worse and he begins to feel nauseated, but pushes through regardless, leading to further disequilibrium. His vulnerability was further increased by his decreased adaptive capacity related to not being able to take enough work breaks to attenuate his HRI symptoms, inadequate access to appropriate fluid replacement and the lack of established practices and early action plans for worker symptom surveillance that might have detected his progression down the HRI cascade before severe HRI occurred.

Discussion

This framework is particularly useful for conceptualizing future directions that can prevent heat illness, decrease vulnerability to heat and promote physiologic equilibrium because it aids in the systematic identification of timepoints when interventions to promote health and prevent heat-related disease could occur in vulnerable populations. The heat hazard is the input into the system and not necessarily a modifiable entity. Nevertheless, the heat hazard poses a valuable opportunity for public health intervention. The modifiable components of the framework will be in the dynamics of the summation of vulnerability: exposure, sensitivity and adaptive capacity. Sensitivity is the component of vulnerability that is the least modifiable since these factors are mainly physiologic or social. Modifications to workplace exposure could include self-pacing and altering work schedules to avoid high heat periods of the day as well as the development of heat-prevention regulations that mandate specific work-rest algorithms based upon environmental conditions. Another modifiable component of vulnerability is adaptive capacity in which interventions could be performed to promote on-site action plans to identify workers suffering from HRI and ensure that precautions to reverse HRI progression are implemented swiftly by crew leaders and managers.

The Farmworker Vulnerability of Heat Hazards Framework also acknowledges that there are many aspects that comprise vulnerability and places all three components of vulnerability at the same level. Thus, even if only one aspect is altered, such as duration of exposure time through working earlier hours, this action could have meaningful effects if its impact is large enough t to decrease vulnerability and tip the scales towards physiologic equilibrium rather than disequilibrium.

A shortcoming of this model is that it needs to be employed and further tested in vulnerable worker groups. Additionally, further research may expand the model by identifying additional factors, including relationships or interactions between model components that may contribute to increased risks to human health associated with climate change. This model provides a useful framework to assist scientists, clinicians, and policy makers in our understanding of the complexity of the human response to increasing environmental heat, particularly among vulnerable working populations.

Conclusion

The Farmworker Vulnerability to Heat Hazards Framework, provides a useful inventory of the factors related to the occurrence of heat injury and heat-related illness in response to heat stress. This model also displays the concept of vulnerability as a dynamic and changeable modifier of heat stress based upon the presence and magnitude of the factors of vulnerability including exposure, sensitivity, and adaptive capacity. Finally, the heat stress response of equilibrium or disequilibrium acknowledges the true symptomatic and physiologic responses that can occur in response to heat hazards rather than merely relying on a body temperature reading that does not fully explain what is occurring at the level of the individual. Therefore, the Farmworker Vulnerability of Heat Hazards framework aids in operationalizing and characterizing heat stress in farmworkers in planning further studies.

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PAPER 2

Heat Exposure in Central Florida Fernery Workers: Results of a Feasibility Study

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Abstract

Objective: The objective of this study was to determine the feasibility of field-based biomonitoring of heat-related illness (HRI) phenomena in Florida farmworkers. We determined feasibility through participant interviews regarding acceptability, data capture, recruitment and retention, and observed barriers and challenges to implementation.

Methods: Study participants were employed in fernery operations in northeast Central Florida where ornamental ferns are grown and harvested in a seasonally high heat environment. In this pilot, a total of 43 farmworkers participated during Summers 2012 and 2013 and measurements included: body core temperature, heart rate, energy expenditure, urine and blood osmolality, and self-reported HRI symptoms.

Results: Data capture was approximately 90%. Participants reported that the study methods were non-obtrusive to their work, and that they were comfortable with study measures.

Conclusions: These results open possibilities for characterizing heat-related illness utilizing physiologic biomonitoring in vulnerable occupational groups.

Introduction

With 9 out of the 10 hottest years on record occurring in the last decade, excessive heat is becoming a global public health priority (1). Mounting scientific evidence has documented the adverse health effects of global warming, gaining the attention of public health organizations worldwide. The effects of heat on humans has a physiological basis with heat exposure leading to heat stress and potentially heat strain (2). Farmworkers are a vulnerable population with a 20 times higher risk for heat-related death compared to other occupational groups (3). Farmworkers are subjected to adverse conditions, including working in high temperature environments for extended periods. Unfortunately, farmworkers often lack the ability to modify their work environments, may not have access to shade or adequate drinking water in the fields, and are typically paid per volume harvested, with little incentive to take frequent work breaks (4).

There is limited literature detailing actual environmental monitoring and physiologic assessment of individuals working in real-world, high heat environments. Most of the research on the physiological effects of working in high temperatures has been conducted in controlled laboratory environments. While surveys of U.S. farmworkers document their perception of heat in their work environment and self-reported symptoms (5,6,7,8), actual physiologic assessments and the monitoring of heat strain in individuals while working in hot agricultural environments are needed and timely. Field studies are needed to examine physiological responses to rising work temperatures in combination with the work-related metabolic demands. However, feasibility of physiologic biomonitoring of heat strain during the workday has not been determined to date.

This paper describes the results of a pilot study to determine the feasibility of implementing a research protocol that includes field-based, physiological biomonitoring of farmworkers. The objectives of this pilot study were to:

1) Determine the potential level of farmworker participation in a field-based biomonitoring study including recruitment, retention, and participation in study protocols;

2) Determine feasibility and participant acceptability of occupational, field-based methods and equipment, including measures of dehydration, heart rate monitoring, ingestion of a core temperature biosensor and actigraphy; and

3) Describe barriers and challenges for heat studies with hard-to-reach vulnerable populations and identify strategies to for future studies to overcome them.

Methods

Targeted Population

Study participants were farmworkers employed in fernery operations in northeast Central Florida where ornamental ferns are grown and harvested in a seasonally high heat environment. Ferneries are horticultural industries and fernery workers are considered agricultural laborers for the purposes of federal regulation (9). Although specific agricultural industries in Florida may have distinct employee populations and workplace risks, general occupational health and safety factors such as chemical use, repetitive motion, and heat exposure exist across all agricultural industries. Ferneries are fields of fern grown under porous black shadecloth (saran) or occasionally under natural tree cover depending upon the species of fern. The partially enclosed environment is characterized by high ambient temperatures due to solar radiation that is absorbed by the shadecloths, solar radiation that travels through the shadecloths, high humidity, and diminished air circulation (7). Ferns are harvested 12 months of the year in Volusia County, Florida, the most humid state in the United States (10). Per the most recent climate data from the

Florida Climate Data Center from 1981-2010, the normal maximum ambient temperature for Volusia County from May through August is 88.2°F (31.2°C) (11).

These temperatures, in combination with high humidity, create a very hot working environment. Additionally, fernery workers use self-provided, low cost, impermeable clothing (e.g., plastic trash bags tied around farmworker torso) to protect themselves from moisture arising from close contact with the harvested plants (7). Workplace demand for productivity (i.e., daily pay is “piece rate” - based on the number of harvested fern bunches) pushes fernery workers to high physical exertion levels, compromising the body’s natural compensatory mechanisms for dissipating heat (7).

Over the course of two summers (2012 and 2013), community health workers (*promotores*) hired by the Farmworker Association of Florida (FWAF) recruited individuals to participate in the pilot study. Community workers (*promotores*) selected by the leadership of the FWAF assisted with recruitment, data collection, and translation of study materials. All *promotores* completed human subjects training, and received training on all study procedures including administering informed consent, surveys, and exit interviews, and collecting biological measures.

Using strong community networks and contacts, the FWAF reached out to the community to inform workers about the study. Persons interested in the study were screened for eligibility at the FWAF office to create a convenience sample. To participate in the study individuals had to be 18-54 years of age, currently working in a fernery for at least the last month, of Latino descent, and able to speak English or Spanish. Individuals were not eligible for the study if they had a history of a disease of the esophagus, previous digestive tract surgery, swallowing difficulties, had been diagnosed with diabetes mellitus type II, had been diagnosed with hypertension, were pregnant, or weighed less than 37 kilograms or 80 pounds.

Through the informed consent process, potential study participants were told what the study would entail and were asked to participate for three days of monitoring during their usual work activity. All study explanations were provided in the participant's native language. Participants were told in advance that they would be compensated $120.00 for the three consecutive days of monitoring and during the enrollment (baseline) visit. After the baseline visit and during each monitoring day, participants received $30. The purpose of the compensation was to offset the time required for the study visits and the time and costs required to drive to the FWAF for study visits which although was on the way to the worksite for all participants was often 30 minutes away from participant homes. This amount of compensation was based upon the compensation provided for similar time, travel and participation requirements of previous studies with the FWAF. All study procedures were approved by the Emory University Institutional Review Board.

We enrolled study participants in small cohorts of 3-5 people each, and testing took place over the course of 2.5 weeks in 2012 and four weeks in 2013. The biomonitoring protocol consisted of four major components: core body temperature monitoring, heart rate monitoring, workday actigraphy, and pre- and post-workday dehydration. This biomonitoring took place during an evening baseline visit followed by three workdays during which the participants came to the study location before and after work for data collection and to don equipment. The study period ended with an exit interview to gauge participant feedback.

Core Body Temperature Monitoring, Ingestible sensor, and Heart Rate Monitoring

The optimal method of measuring core body temperature is via rectal temperature, but intestinal temperature measurement has been shown to be an equally valid, less invasive method that is highly correlated to rectal temperature (r=0.86) (12). In addition to accuracy, this method is discreet in the field and provides more frequent measurements than would be feasible via manual tympanic or rectal temperature. The CorTemp® Wireless Core Body Temperature Monitoring Data Recorder (HQInc., Palmetto, FL) can be concealed under clothing, worn at the small of the back, and secured with a neoprene belt. The use of this instrument requires the participant to swallow a temperature sensor that is approximately the size of a large vitamin pill. Farmworkers ingested the temperature sensor the evening before each of the study days due to early morning work start times. Sensors were each calibrated for individual CorTemp® data recorders to ensure correct readings. However, the ingested temperature sensor has a range of only two feet. Therefore, if the belt holding the CorTemp® data recorder were to fall down, the sensor could become out of range.

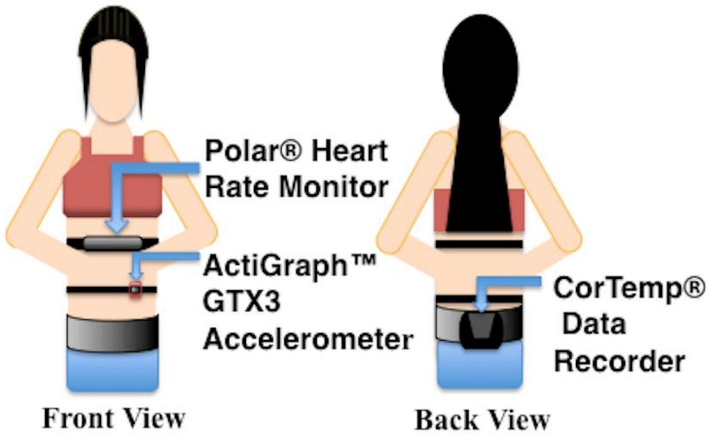
The Polar® T31 non-coded transmitter (Polar Electro, Kempele, Finland) is worn around the upper abdomen at the level of the lower sternal border, and contains heart rate electrodes to gather measurements necessary for PSI calculation in the field. This index measures an individual's degree of heat stress through physiologic readings of core body temperature and heart rate and can be utilized to measure heat stress at any time during the exposure (13). This index yields a score from 0 to 10, with 10 being the most severe degree of heat stress and a value of 0 indicating little to no heat stress (13). The heart rate reading from the Polar® T31 is transmitted to the CorTemp® data recorder.

Actigraphy

More intense work requires more effort and thus more metabolic energy. This internal metabolic energy is paramount because the body's physiological response to heat is partly borne of the environment and partially sourced by the individual's metabolic processes (14,15). By estimating an individual's energy expenditure, the amount of metabolic heat being created can be quantified. We utilized the ActiGraph GTX3+ (ActiGraph, LLC, Pensacola, FL), an accelerometer that can measure tri-axial accelerations from -3g to +3g, yielding counts per a single epoch (16). The raw counts, body mass of the individual and vector magnitude, in three directions, can be translated into energy expenditure (EE) (17). The software package, ActiLife 6, was used for initialization and calibration of the accelerometers as well as downloading raw activity counts, provided several EE prediction equations options for use. The "VM3 Combination (2011)" option, selected for use in this pilot, yields energy expenditure in kilocalories by using the Freedson Adult VM3 equation (18) when counts are greater than 2453 in combination with the Work-Energy Theorem formula (19) for counts less than 2453 (17).

An advantage of this instrument is its easy concealment, beneficial for farmworkers as it does not draw the attention of supervisors or co-workers at the worksite nor interfere with work tasks. To assess the preferred placement of the device, in 2012, study participants wore it on the wrist as recommended by ActiGraph to capture the predominant movement of the upper body, which is the primary movement in fern cutting. In 2013, the farmworkers were asked to wear the accelerometer on a belt around the waist and placed at the axillary line, the center of body mass, which is a typical placement of the apparatus in validation studies (18). Figure 1 shows the placement of the actigraphy, core body temperature and heart monitoring equipment.

Figure 1. Placement of Biomonitoring Equipment in Summer of 2013



Dehydration Measurement

If a worker becomes dehydrated, blood volume decreases, therefore decreasing their ability to dissipate heat via sweating and convection on the skin surface. Minimum daily water needs for men and women are 3.7 L and 2.7 L respectively; however, some individuals may require more fluid intake due to the strenuousness of their daily activities (20). Dehydration is indicated when there is a body mass change of more than a 2% from pre- to post-activity (21). However, for assessing small changes in hydration over several time points, it is recommended to use plasma osmolality, urine specific gravity and body mass concomitantly, with a minimum of at least two of the three measures (21). We gathered initial weight and then pre-workday weights on three consecutive days. Participants were also to disrobe and wear a gown to improve body mass measurement accuracy.

The optimal measure of hydration status is plasma osmolality via a laboratory osmometer which would require a venipuncture. Plasma osmolality can be assessed through a fingerstick method such as the i-STAT® Handheld Blood Analyzer (Abbott Laboratories, Abbott Park, Illinois), which provides concentrations of sodium (Na), potassium (K), blood urea nitrogen (BUN) and glucose, from which values of plasma osmolality can be calculated using the equation (22):

$$\text{Osmolality} = 1.86(\text{Na} + \text{K}) + 1.15(\text{Glu} / 18) + (\text{BUN} / 2.8) + 14$$

Plasma osmolality via fingerstick and the i-STAT Handheld were selected for this study because laboratory-based osmometers are costly, have more stringent calibration needs, and would require immediate analysis after venipuncture since osmolality increases with time after blood is drawn. Also, fingersticks are a less painful and less intrusive option. Plasma osmolality via fingerstick was not added until 2013 due to cost.

Also in 2013, we added a point-of care Osmolality Meter (Osmocheck®) (Vitech Scientific Ltd, West Sussex, UK) to assess urine osmolality at the pre- and post-workday visits. For pre-workday samples, participants were provided with a clean urine specimen collection cup the evening before and instructed to collect a first morning urine sample to bring to the pre-workday visit.

Exit Interviews

At the end of post-workday data collection on Day 3, we invited participants to take part in a 15-minute exit interview. The purpose of the exit interview was to assess acceptability of the study methods. Additionally, the exit interviews provided monitoring regarding any methods deemed unacceptable by study participants so that methods could be changed or the study discontinued. We obtained consent from each participant and the exit interviews were conducted in Spanish by a *promotora*. Each exit interview was audio-recorded to ensure that comments and feedback were captured accurately. These audiotapes were then translated and transcribed in English. Questions included:

(1) Were the visit times acceptable?

(2) Did you feel that your job was in danger because of your participation in the study?

(3) Were you comfortable during the study? Which measurements did you find to be uncomfortable?

(4) Was today a typical workday for you? If not, why?

(5) Did you feel that you benefitted from participation?

(6) Would you advise others to participate in a similar study?

Results

Recruitment and Participation

The first objective of the pilot study was to determine the level of farmworker participation in a field-based biomonitoring study, including recruitment, retention and participation in study protocol. During the summers of 2012-13, 69 fernery workers were contacted by *promotoras* and asked if they were interested in participating in the study, with 68 (98.6%) expressing interest in participation. Only one potential participant declined to participate due to uncertainty regarding the physiological monitoring. Of the other 68 workers approached to participate in the study, 37% (n = 25) were not enrolled. Reasons for not participating included: (1) currently pregnant, (2) history of type II diabetes, and (3) choosing not to participate because spouse was ineligible to participate. Other individuals reported having work schedules incompatible with the study collection days or did not have transportation to the testing facility because they carpooled with other workers. Characteristics of the 43 farmworkers participating in the pilot study are shown in Table 1.

Table 1. Descriptive Characteristics of Study Participants, 2012-2013

	2012 (n=20)	2013 (n=23)
Age (mean [SD])	36.4 years (8.4)	35.8 years (7.4)
Gender		
Men	8	5
Women	12	18
Years Working in Agriculture (mean [SD])	14.21 [4.44]	12.78 [4.18]

The pilot study was designed to help us determine how long it would take to enroll a projected goal of 20 participants each Summer, based upon funding. Recruitment began two weeks before the testing periods, continuing throughout data collection. We found attrition to be minimal even though it involved three days of testing with 40 of the 43 participants completing the entire testing protocol (91.4%). Of the three individuals not completing the protocol, one individual had missing data for one pre-workday visit due to being late to start work and two experienced work schedule cancellations resulting in not being able to complete all three days of testing.

Feasibility of Core Body Temperature Monitoring, Ingestible sensor, and Heart Rate Monitoring

The CorTemp® data recorder, as well as the Polar® S610-HR monitor, could be concealed under clothing, did not interfere with work tasks, and were acceptable to the participants. This combination is thus a culturally acceptable, discreet and reliable method for assessing real-time core body temperature throughout the workday.

One of the challenges with using the CorTemp® device is the variation in the time it takes for the pill to pass through the alimentary tract. It is possible that the pill could be excreted while the participant was at work. In 2012 and 2013, participants were instructed to ingest the core body temperature sensors the evening prior to workday one and at the post-workday visit on workdays one and two, if the temperature sensor was no longer present. If the temperature sensor was still present, no additional sensor was administered. Of the 43 participants in 2012 and 2013, three had at least one incidence of passing the temperature sensor before workday data could be collected; this prohibited the capture of core temperature data for these participants during the study period. Three additional participants had at least one incidence of excreting the temperature sensor before the end of the workday, attenuating data collection for those workdays and prohibiting the collection of two days of workday temperature data. With a three-workday collection protocol, the capture of two days of core temperature and heart rate data was achieved in nearly 90% of participants. Time constraints for data collection periods and participant work schedules required the use of 3 consecutive workdays.

Conversely, even though the target was to gather at least two days of workday temperature data, some participants did not pass the temperature sensor for up to 72 hours. We also experienced incidences of equipment failure with the Polar® heart rate monitor, which resulted in intermittent loss of heart rate data points. Fortunately, heart rate data readings occurred at 30-second intervals, providing ample data for analysis on those study days. Figure 2 shows an example of the readings of one participant in one workday period.

Figure 2. Sample CorTemp™ Raw Data for One Participant in 2013

Date	Time	Internal Temp (°F)	Heart Rate (BPM)
7/23/2013	11:07:12	100.22	108.90
7/23/2013	11:07:42	100.23	112.60
7/23/2013	11:08:12	100.23	99.60
7/23/2013	11:08:42	100.25	110.20
7/23/2013	11:09:12	100.25	101.50
7/23/2013	11:09:42	100.25	102.80
7/23/2013	11:10:12	100.27	117.50
7/23/2013	11:10:42	100.29	99.40
7/23/2013	11:11:12	100.29	118.20

Feasibility of Activity Monitoring

Our pilot study revealed that the ActiGraph™ GTX3+ monitor was easy to conceal under clothing and did not interfere with work tasks. A Phillips Respironics Mini-Mitter Actiwatch™ (Koninklijke Philips, Amsterdam, Netherlands) was utilized initially due to availability at no cost, but it did not easily provide the needed energy expenditure calculations, as this model was geared towards sleep monitoring. Sleep monitors are not satisfactory for activity monitoring in HRI biomonitoring, because they do not typically provide data that can be easily converted to energy expenditure. Additionally, the tri-axial monitoring provided by the GTX3+ monitors by ActiGraph™ provide a more comprehensive picture of worker energy expenditure, which can include multiple types of movements. A summary of ActiGraph™ data and energy expenditure results over the 3-day study period for a participant is shown in Figure 3.

Figure 3. Sample Energy Expenditure Data for One Participant in 2013

	Day 1	Day 2	Day 3
Start time (Self-reported)	07:40	07:40	8:00
Stop time (Self-reported)	15:00	13:00	13:00
Total energy expenditure (EE) for workday* (kcal)	1906.5	1674.8	802.3
Average hourly EE (kcal)	260.1	314.2	160.5

Feasibility of Dehydration Measurement

In this pilot work, we assessed the feasibility of each of three measures of dehydration: body mass, plasma osmolality, and urine specific gravity. Measurement of pre- and post-workday body mass presented logistical challenges. In order to collect body weight measurements, participants had to remove their work clothes down to undergarments and wear a gown. Disrobing and body mass measurement took place privately in the FWAF office bathroom, but disrobing increased study visit duration, when the time frame was already tenuous and was inconvenient for the workers. Additionally, strict intake and output measurements were not feasible during the workday, decreasing the validity of a participant's hydration status based upon body mass change calculations. Given the difficulties we encountered in measuring body mass change initially, in 2013 we added concomitant measures of pre- and post-workday blood osmolality and urine osmolality using the i-STAT® analyzer and the Osmocheck®.

There were no issues to report regarding urine sample collection via first morning urine brought from home or post-workday urine collection at the office. Blood osmolality was more challenging due to the procurement of blood via fingerstick. Workers' fingers were often thickened from years of work in the ferneries, and at post-workday visits their fingers were often wet and cold from work. The i-STAT® analyzer equipment used was rented from a third-party equipment rental company and occasionally failed due to printer malfunction and cartridge incompatibility. With printer malfunction, some of the laboratory results appeared on the analyzer screen, but when the results were printed for data collection, these results were not present, resulting in data loss. An example of dehydration results from a participant in 2013 is shown in Figure 4.

Figure 4. Sample Dehydration Assessment Data for One Participant in 2013

	Baseline	Day 1		Day 2		Day 3	
		Pre-Workday	Post-Workday	Pre-Workday	Post-Workday	Pre-Workday	Post-Workday
Blood							
Glucose				136	94	96	103
Sodium				140	141	143	142
BUN				16	18	18	14
Calculated Blood Osmolality				293	294	286.74	298
Urine							
Specific Gravity	1.028	1.027	1.029	1.017	1.029	1.018	1.024

Qualitative Assessment Results

Following participant exit interviews, recordings were transcribed in Spanish and then translated into English by the *promotora* conducting the interviews. English transcripts were formatted and cleaned for analysis. Responses to exit interview questions about the feasibility of methods that were "yes" or "no" were tallied. Responses to open ended questions that generated more in-depth comments about factors such as overall satisfaction with the study measures, perceived benefits of participation, and thoughts regarding encouraging other community members to participate in the study in the future, were examined for and grouped by common themes. These responses were then studied for quotes from participants that seemed to represent the responses of the group as a whole (Figure 5). Of the 43 study participants, 98% agreed to participate in the exit interview.

Figure 5. Sample Participant Quotes from Exit Interviews

"I think it was a good thing because in spite of us being immigrants you show concern about our health, studying the possible causes that might impact our systems while we are at work. And…I think that's all. And… yes, I'm happy for that."

"I believe there is a benefit for us. To know what problem could cause us to be exposed to such a heat, I think it is good that they want to know it and if there is something that can be done, I do believe it could be in our future benefit."

"I hope we can find a way for the cutters to have less time working while it is hot. I wonder if working in the heat affects your health and I want to know more about what can be done to protect workers, especially pregnant women. If we can do something for them, it would be good."

"I feel that it is necessary to know what could affect us in the environment that we have to work in."

"If in time we learn about what affects us in our place of work and give us more ideas and Improvements. I think of this like a great thing. I suggest continuing with this study."

"I liked it because I wanted to know more, besides I gained a lot of confidence and increased my self-esteem after the experiment. In other words it is a benefit for everybody."

In terms of factors related to feasibility, all participants found the visit times to be acceptable, citing that they were compatible with their regular work schedules. None of the participants reported feeling that their job was in danger due to their participation in the study and a few cited their appreciation of the discreetness of the study measures, the non-interference with work, and the understanding that their participation was confidential. The only results of the exit interviews that prompted improvements were related to increased privacy at the field office to improve comfort during the study, which was mentioned by one exit interview participant, leading us to eliminate the pre-and post-workday body weights because this measure required disrobing.

In recognition that feasibility is also related to how participants valued the study, we examined perceived benefits from the study, including increased interest in heat-related knowledge and potential related health issues. Participants were pleased to receive their daily maximum core body temperature measurements, BMI and body composition that were collected over the study period to include as part of their personal health record, along with worker-oriented educational materials providing guidance for preventing heat-related illness from the Occupational Safety and Health Administration (OSHA).

Data Capture

As a component of this pilot work, we examined our ability to capture a large amount of narrative and physiological data. In 2012, although we projected that data collection for the baseline visit to intake five subjects would take 1.5 hours for each subject, we found it actually required 2.5 hours on average for each subject with 3 *promotoras* and 1 nurse researcher involved. Workday data collections schedules preceded workday start times by a few hours, ranging from 4:00AM to 7:30AM. Participants returned to the FWAF office for post-workday visits as early as 10:00AM and as late as 6:30PM. We averaged processing five participants in each pre- and post-work period, with each visit requiring an average of 15 minutes with two field personnel, a nurse researcher and a *promotora* working. Time required for baseline and workday study visits was similar in 2013. Under the 2012 and 2013 protocol in which the temperature sensor was ingested in the evenings, three days were required to capture two full days of core temperature data.

In this pilot study we were able to use continuous physiologic monitoring using the CorTemp® data recorder and CorTrackII® software (HQInc., Palmetto, FL) to record and download simultaneous core temperature and heart rate data yielding both graphical and quantitative measurements over the workday. In 2012 and 2013, we instructed participants to ingest the core body temperature sensors with a light meal in the evening prior to workday one and at the post-workday visit on workdays one and two if the previously administered sensor had been excreted from the digestive tract.

According to the American Conference of Governmental Industrial Hygienists' Threshold Limit Value (TLV), the recommended core temperature limit for workers, is 38.0°F (100.4°F) (23). In 2012, 13 out of the total 20 participants exceeded the TLV on at least one study day. The highest core temperature recorded was 38.9°F (102.0°F). Essentially, over half of the participants displayed at least one point at which their core body temperature exceeded the TLV. In 2013, 17 out of the 23 participants exceeded the TLV on at least one study day.

Discussion

Despite the challenges faced in this pilot study, we felt that the physiologic measures proposed for data capture were feasible. Since we were able to collect approximately 90% of attempted anthropometric and biomonitoring data measures, we deemed data collection to be successful. Table 2 contains the proposed best methods for a future larger study.

Table 1. Proposed Best Methods for Future Studies

Measurement	Method
Environmental Heat Stress	Wet Bulb Globe Temperature (WBGT) calculated from regional weather data if on-site WBGT measurement is not feasible
Heat Strain	Physiologic Strain Index via simultaneous heart rate (HR) and body core temperature measurement (T_c)
Work Intensity	ActiGraph GTX3+ with waist placement utilizing the most appropriate equation for estimating energy expenditure
Dehydration	Serial measures of pre- and post-workday blood osmolality and urine osmolality

Lessons Learned and Next Steps

Differing rates of passage of the intestinal temperature sensors created challenges. For instance, in some circumstances we only obtained two days of testing versus three. Administering the sensor pill during the post-workday testing period was not an optimal practice for participants finishing work by 4pm or earlier. To address this issue we are adapting our protocol for future studies to instruct participants to take the sensor pill after they return home during the time of their evening meal. If we then find the sensor pill had already been excreted during the next day's pre-workday visit, participants will be given a new sensor pill before going to work.

Wet bulb globe temperature (WBGT) is an index used to quantify environmental heat stress and is commonly utilized in exposure assessment for occupational environments (23, 24). Given the protection we assured the study participants, we did not request that they try to obtain WBGT readings in their work environments. However, in lieu of workplace WGBT measurements at the fernery sites, we utilized public data collected from the Florida Automated Weather Network (FAWN) network that reports meteorological data, including wet-bulb temperature, dew point, relative humidity, wind speed, solar radiation and ambient temperature, at 15 minute intervals throughout each 24-hour period. These data can be used to calculate estimated WBGT (25). Quantitative documentation of the microclimate inside fernery operations is not available in the literature, but would be an important addition to future studies because workplace microclimates can deviate from the general climate of the surrounding area (26). Plans for future studies include the use of the iButton (Maxim Integrated Products, Inc., San Jose, CA), which is a small personal temperature logger that can be worn attached participants' clothing to collect environmental data at individual worksites. This penny-sized temperature logger, similar to a fob, can provide measurements of ambient temperature and relative humidity (RH) (27). We will be comparing these values to those collected by the Florida Automated Weather Network (FAWN) network. More creative methods are needed for collecting direct WBGT at the worksite with the current access constraints.

The coupling of heart rate and temperature for physiologic monitoring of heat strain is advantageous because this method allows for the calculation of PSI beyond core temperature readings supporting its continued use in future studies. This index is appropriate even when workers are wearing personal protective equipment (PPE) or different clothing, because of its individualized nature, alleviating the need to adjust for clothing differences amongst individuals (28). Another advantage is that the PSI is an instantaneous measure that can be used to examine a particular period of interest (i.e. recovery after rest breaks, high heat times) during the workday.

For future studies, we will continue to use the GTX3+ monitor to capture work intensity, in conjunction with the companion ActiLife 6 software. The ActiLife 6 "VM3 Combination (2011)" option provided a versatile approach to energy expenditure calculations capturing participant movement across varying work intensities including those with counts per minute of less than 2453 (17). The GTX3+ should be worn at the waist and placed on one consistent side to ensure the most valid data (18).

Our dehydration measurement feasibility findings support the continued utilization of blood osmolality measurements via fingerstick, and we will be improving the ease of collection by utilizing microwaveable warming packs for participants to hold prior to blood sample collection via fingerstick to warm their fingers and encourage blood flow. Also of note is that i-STAT® blood analyzers need to be procured from Abbott Laboratories, rather than third party suppliers who offer rentals of older models, that may not have updated software, customer support, or accurate information regarding the procurement of compatible i-STAT® Handheld analyzer cartridges.

Research in farmworker populations can be challenging, although the extent of the challenges varies between states. One factor affecting risk is grower cooperation. In the absence of grower cooperation granting worker access, the worker assumes more risk. Because we were engaging the FWAF to work with the communities, it was not politic for us to pursue grower permission to access workers because it would not have been in line with the wishes of the FWAF. This presents a possible bias in our sample. However, since no workers felt their jobs were endangered from participation, and feedback indicated appreciation for the discretion of the protocol, future studies in these same communities may not be as affected by this bias potential.

Conclusion

Methods described in this paper were utilized in a pilot study during Summers 2012 and 2013. The results of this feasibility study demonstrate that comprehensive, real-world physiologic biomonitoring outside the confines of a laboratory setting is feasible, opening new possibilities for characterizing and monitoring HRI in vulnerable populations. Moreover, our results reinforce the need for heat strain assessment in this vulnerable population. Research on occupational exposure to high heat environments is timely and will add to the growing body of evidence highlighting the association between climate change and the risk of extreme heat-related health outcomes.

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PAPER 3

Elevated Core Temperature in Florida Fernery Workers: Results of a Pilot Study

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Abstract

Objective: The objective of this analysis was to characterize occupational heat exposure and key vulnerability factors and the physiologic heat stress response in a sample of fernery workers.

Methods: Eighty-six workdays from forty-three fernery workers were examined from a feasibility study of heat-related illness in farmworkers that took place during the Summers of 2012 and 2013. The key outcome measure was whether a participant's body core temperature (T_c) reached or exceeded 38.0ºC (100.4ºF). After characterizing average daytime wet bulb globe temperature (WBGT), workday energy expenditure, workday duration, years working in a fernery, age, female sex, body mass index (BMI), a logistic regression analysis utilizing a generalized estimating equations approach was performed to examine these potential predictors.

Results: Participant T_c exceeded 38.0ºC on forty-nine (57%) of the workdays examined. Workday energy expenditure was found to be a significant predictor of T_c exceeding 38ºC (100.4ºF) (OR=1.08, $CI_{.95}$[1.005,1.15]). When examined alone, being female was not found to be a significant predictor (OR=2.82, $CI_{.95}$[[-0.11, 8.85]); however, when examined in the model with energy expenditure, sex was found to be a significant predictor (OR=5.37, $CI_{.95}$[1.03,18.30]) of a participant's T_c reaching or exceeding 38.0ºC. All other potential predictors examined were nonsignificant in the model.

Conclusions: Women were found to have a substantially increased odds (OR 5.37, $CI_{.95}$[1.03,18.30]) as compared to men for their body core temperature meeting or exceeding 38.0ºC when adjusting for workday energy expenditure, indicating a higher risk for heat-related illness than men in this sample.

Introduction

In 2014, the Intergovernmental Panel on Climate Change, a group of expert scientists who provide regular assessments of the available evidence surrounding climate change, charged with providing evidence to support policy makers in their decisions surrounding climate change adaptation and mitigation, published a report entitled *Climate Change 2014–Impacts, Adaptation and Vulnerability* (1). This report emphasized the importance of planning future climate change adaptation measures to help alleviate the potential human health risks in the face of a changing climate with more extreme weather events, leading to a greater risk of injury from extreme heat. To plan for future climate change adaptations, current health effects in populations affected by climate conditions must be characterized. Farmworkers engage in heavy outdoor labor (2) and have been found to experience heat-related death at a rate nearly 20 times that of all civilian workers in the United States (3). To prevent further loss of life in the face of climate change projections, studies to characterize the extent of heat-related illness in farmworkers are needed.

With the goal of characterizing heat-related illness in a population of Florida farmworkers, the Farmworker Association of Florida (FWAF) partnered with Emory University to implement a pilot study in Pierson, Florida. The aims of that study were to (1) assess the feasibility of conducting sophisticated field-based biomonitoring of heat strain in Florida farmworkers; (2) characterize occupational heat exposure and key vulnerability factors in Florida; and (3) characterize the physiologic heat stress response of farmworkers in Florida. The results of the feasibility aim of the study have been reported previously (4). The current analysis encompasses the remaining two aims. The study design was guided by components of the Farmworker Vulnerability to Heat Hazards Framework (5), including the hazard (environmental heat stress), workplace exposure (duration of work and work intensity), sensitivity factors (age, years working in agriculture, body composition, and sex) and heat stress response (body core temperature reaching or exceeding 38ºC (100.4ºF)).

Methods

Participant Recruitment

The data for this analysis was collected from a pilot study conducted during the Summers of 2012 and 2013 (4) by Emory University and the Farmworker Association of Florida. Participants were recruited by community health workers, *promotoras*, through community ties and networks of the Farmworker Association of Florida (FWAF) in Pierson, Florida. Participants were pre-screened for eligibility via phone or in person and then were enrolled at the baseline visit after consenting to participation in the study. Participants were compensated with a $30 grocery gift card at baseline and for each of the 3 study days for their participation. Participants eligible for the study were: (1) able to speak Spanish or English; (2) 18 to 54 years of age; (3) working in a fernery for at least the last month; (4) without a history of diagnosed diabetes mellitus type II, hypertension or any disorders of the digestive tract; (5) not pregnant; and (6) without a pacemaker. Fernery workers harvest ornamental plants, like leatherleaf fern, under large structures made of black plastic mesh supported by metal posts or under large trees (6). All study procedures were approved by the Emory University Institutional Review Board.

Data Collection and Analysis

Participants attended an evening baseline study visit followed by three consecutive workdays of biomonitoring. All study visits took place at the at the FWAF Office. During the baseline study visit, participants were consented after being read the consent in English or Spanish, answered sociodemographic questions including their age and the number of years they had worked in a fernery, and participated in biologic measurements including height and weight to yield body mass index. In 2013, body fat percentage skin fold measurements were added to the biologic measurements. After the baseline visit, participants were given a CorTemp® (HQInc., Palmetto, FL) temperature sensor pill to swallow in preparation for body core temperature readings, via intestinal temperature, the following workday. On the three workdays captured in the study protocol, participants came to pre-workday visits to don biomonitoring equipment.

Biomonitoring equipment worn by the participants included an ActiGraph GTX3+ (ActiGraph, LLC, Pensacola, FL) to capture energy expenditure, the CorTemp® Data Recorder (HQInc., Palmetto, FL) to record CorTemp® pill sensor readings and heart rate readings at 30 second intervals, and a Polar® T31 non-coded transmitter (Polar Electro, Kempele, Finland) to detect and transmit heart rate. At the end of the workday, participants returned to the Farmworker Association of Florida office where they doffed this equipment.

Key Outcome Variable. The physiological limit for heat strain as set by the American Conference of Governmental Industrial Hygienists (ACGIH) is 38.0ºC (100.4ºF) for unacclimatized workers while workers that are acclimatized and have been medically selected, the physiological limit is set at 38.5ºC (101.3ºF). For this analysis, 38.0ºC was selected due to the pilot nature of this study and the limited ability to know a participant's medical status. Acclimatization is thought to occur by 14 days in the majority of individuals (7). The key outcome variable for this analysis was whether a participant's core body temperature (T_c) reached or exceeded 38.0ºC during a workday. This key outcome variable was derived from the duration of time a participant's core body temperature (T_c) reached or exceeded 38.0ºC during the workday which was determined by the sum of the time during all bouts the participant's core body temperature exceeded 38.0ºC. A time bout began when two T_c readings within 1 minute of each other reached or exceed 38.0ºC, and a time bout ended at the next incidence of two T_c readings, within 1 minute of each other, falling below 38.0ºC. Due to the pilot nature of this study, varying core temperature intervals were used including 20 second, 30 second and 60 second intervals, with the 30 second interval predominating. Core body temperature readings were truncated by thirty minutes on each end of the workday to account for travel time from the FWAF office to the worksite.

Covariates. To capture environmental heat exposure, daytime wet-bulb globe temperature was estimated from meteorological data utilizing hourly averages of dry bulb temperature and psychometric wet bulb temperature (8), throughout the workday from the Florida Automated Weather Network (FAWN) (9). Meteorological data was truncated to include from 4 a.m. to 6 p.m. to encompass the daytime working hours of the participants. Core temperature monitoring time described above was utilized to represent workday duration. Energy expenditure per hour was calculated by dividing workday energy expenditure by the workday duration. The placement of the ActiGraph was changed from the wrist in 2012 to the waist in 2013. Actigraphy was collected for the first group of participants (n=4) in 2012 using an actigraphy device geared towards sleep rather than energy expenditure and was therefore excluded from this analysis.

Body mass index was calculated from height and weight (10) and then characterized into 3 categories [normal= 18.5-24.9, overweight=25.0-29.9, obese=30 and greater]. To calculate body fat percentage calculations, first, body density was calculated using the BD(M-2) formula for males and the BD(F-2) formula for females (11). Body density was used to calculate body fat percentage with the Siri formula (12). The number of years a participant has been working in a fernery was self-reported by participants at the baseline visit.

Statistical Analysis

Data collected were entered into IBM SPSS (version 24) or Microsft Excel (2007)) and were exported to SAS ® (version 9.4) for cleaning, coding and statistical analysis. An alpha level of 0.5 was selected for use in this analysis. Descriptive statistics were examined using means, percentages and plots. To account for participants having multiple workdays a logistic regression analysis utilizing a generalized estimating equations approach was performed to examine predictors of a participants' body core temperature (T_c) reaching or exceeding the physiological limit of 38.0ºC. Empirical standard estimates were used due to the sparsity of the data (13).

Results

The average age was 36 years for participants and these participants had been working in a fernery for an average of 13 years (Table 1). Most participants were female and approximately three-fourths of the sample were classified as obese per their body mass index (BMI). The forty-three participants from the combined summers of 2012 and 2013 yielded eighty-six workdays for analysis. Six additional files would have been available for analysis, but three workdays had core temperature file download error issues, and three other workdays had technical issues with temperature pill readings that prohibited analysis. Three participants were lost completely from the analysis due to a combination of pill passage during the workday and technical issues with core temp files.

Table 1. Demographic Characteristics Among Fernery Worker Participants, Florida, 2012-2013

Characteristic	n	
Age (years)	43	36 years ±8 (range=35)
Gender		
Female	30	70 %
Male	13	30 %
Number of years working in a fernery	42	13±4 (range=20)
BMI(kg/m^2)	37	28.3 ±4.8 (range=18.5)
Body weight category (BMI)	37	
Underweight (<18.5)		0 (0.0%)
Normal weight (18.5-25)		9 (24%)
Overweight (25-30)		15 (41%)
Obese (≥30)		13 (35%)
Body Fat Percentage (%) (2013 only)	22	34±7 (range)

Of the eighty-six workdays in this analysis, participant body core temperature exceeded 38.0ºC (100.4ºF) on forty-nine (57%) of the workdays (Table 2). Table 2 shows the duration of time that those participants' body core temperatures met or exceeded 38.0ºC during the workday, organized by workday. On average, for those who met or exceeded 38.0ºC, the duration of time was 79 minutes (SD=73, range=255). The longest duration of time for meeting or exceeding the threshold was 285 minutes, while others remained at or above the threshold for 10 minutes or less. On workday 2, thirteen out of the fourteen participants had body core temperatures that met or exceeded 38.0ºC. When examined, these participants appeared to have similar characteristics to the sample with 86% female and 14% male, an average age of 36 years (SD=9, range=35), 13 years (SD=9, range=35) working in a fernery, and a BMI of 29.2±4.1 (range=15.5).

Table 2. Heat Stress Response Per T_c Meeting or Exceeding 38ºC

Workday		Body Core Temperature≥38.0°C		Duration of Time Body Core Temperature≥38.0°C if exceeded 38.0 °C (minutes)
	n		n (%)	mean±SD (range)
Workday 1	35	Yes	17 (49%)	57 ± 75 (281)
Workday 2	14	Yes	13 (93%)	118± 72 (229)
Workday 3	37	Yes	19 (51%)	72± 65 (208)

The mean daytime wet bulb globe temperature (WBGT) for the study days was 27.2ºC (81.0ºF) (SD= 0.8, range=3.0). Workday durations for this sample ranged from 2.2 hours to 11.6 hours with a mean workday duration of 6 hours (SD=1.9). Energy expenditure averaged 1714 kilocalories (kcal) (SD=691, range=2828 on workday 1 (n=31), 1470 kcal (SD=680, range=2503) on workday 2 (n=11) and 1299 kcal (SD=799, range=3202) for workday 3 (n=33).

Results for one predictor models that examined each predictor independently for its relationship with the key outcome variable, and two predictor models where each predictor was examined for its relationship with the key outcome variable after being adjusted with energy expenditure, and then female sex are shown in Table 3. When examined as a predictor, average daytime wet blub globe temperature was not found to be a significant predictor in the model (Z=.50, p=.62). When examined individually, female sex was also not a significant predictor (Z=1.77, p=.08), nor was participant age (Z=-0.80, p=0.42), workday duration (hours) (Z=0.49, p=0.62), or years working in a fernery (Z=0.39, p=0.70).

Table 3. Logistic Regression One-Predictor and Two-Predictor Models for Workday Energy Expenditure and Body Core Temperature Meeting or Exceeding 38ºC (100.4ºF)

	One Predictor Models			Two Predictor Models	
				Adjusted with Workday EE[a]	Adjusted with Sex
Covariates	Intercept (SE)	β_1 (SE)	OR [$CI_{.95}$]	OR [$CI_{.95}$]	OR [$CI_{.95}$]
WBGT	-3.90 (8.24)	0.15 (0.31)	1.15 [0.64, 2.12]	0.93 [0.46, 1.87]	1.44 [0.76, 2.73]
Workday Duration (hours)	-0.17 (0.82)	0.07 (0.14)	1.07 [0.81, 1.41]	0.93 [0.68, 1.26]	1.14 [0.87, 1.51]
Workday EE[a] (100 kcal)	-0.64 (0.55)	0.07 (0.04)	1.08 [1.005,1.15]*	----------	1.12 [1.03, 1.21]**
Female Sex	-0.52 (0.51)	1.04 (0.58)	2.82 [0.90, 8.85]	5.38 [1.58,18.30]**	----------
Age	1.29 (1.33)	-0.03 (0.04)	0.97 [0.90, 1.04]	0.997 [0.92, 1.084]	0.97 [0.90, 1.04]
Years Working in Ferneries	-0.05 (0.82)	0.02 (0.06)	1.02 [0.91, 1.15]	1.06 [0.94, 1.21]	1.02 [0.91, 1.15]
BMI	0.20 (1.53)	0.003 (0.05)	1.003 [0.91, 1.11]	1.01 [0.90, 1.14]	0.98 [0.89, 1.09]
Normal	Reference	Reference	Reference		
Overweight	0.11 (0.60)	0.17 (0.71)	1.19 [0.30, 4.76]	0.67 [0.14, 3.29]	1.39 [0.37, 5.24]
Obese	0.11 (0.60)	0.29 (0.74)	1.33 [0.31, 5.69]	1.21 [0.20, 7.26]	1.23 [0.31, 4.91]

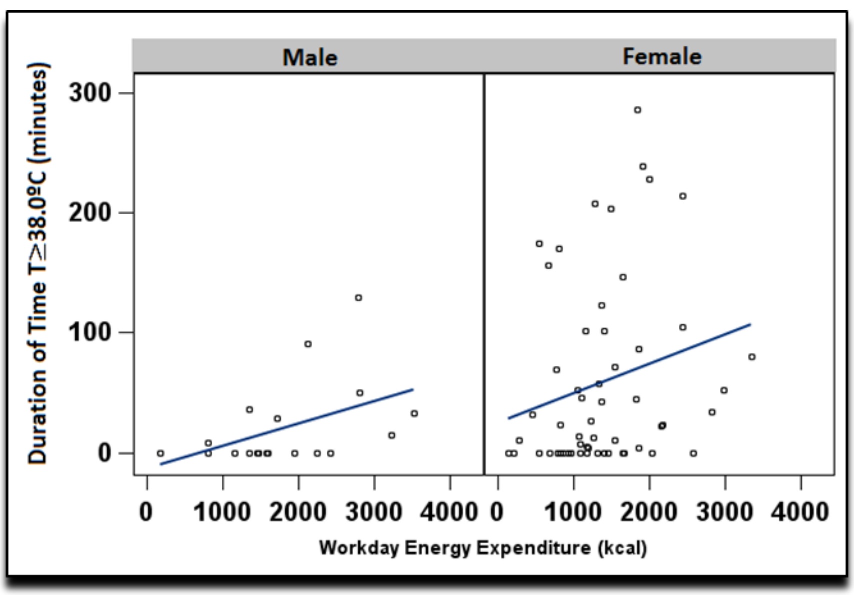
*p<0.5, **p<0.01. [a]Workday Energy Expenditure (EE)

The original variable indicating the body mass index (BMI) was recoded into a categorical variable based upon BMI categories of normal, overweight and obese, using normal as the reference category. Body mass index (BMI) when not categorized was found to be non-significant for the model (Z=0.5, p=0.96). BMI comparing overweight to normal (Z=0.24, p=0.81), and obese to normal (Z=0.39, p=0.69) remained insignificant for the two predictor models. None of the study participants were classified as underweight. Predictor models with energy expenditure and sex were used to examine body fat percentage for 2013. Body fat percentage was not a significant independent predictor (OR=1.003, $CI_{.95}$ [0.89,1.13]) of the key outcome variable or when adjusted with energy expenditure (OR=1.022, $CI_{.95}$ [0.91, 1.15]) or sex (OR=0.88, $CI_{.95}$ [0.77, 1.008]). Body fat percentage and BMI were moderately correlated in 2013 (n=17) with a Pearson's correlation of r^2=0.70, p<0.01.

Total workday energy expenditure (kcal) was the only predictor in the one variable model found to be a significant predictor of a participant reaching the body core temperature threshold of 38.0ºC (Z=2.10, p=0.04). All the predictors that were nonsignificant in the one-predictor model remained insignificant in the two-predictor model except for sex, which became significant when adjusting for energy expenditure (Z=2.70, p=0.01).

A plot of energy expenditure with the duration of time a participant's body core temperature reached or exceeded 38.0ºC (100.4ºF) compared by gender (Figure 1), supports the significant findings of the two-predictor model of sex with energy expenditure. When added, energy expenditure remained significant for the model (Z=2.58, p=0.01) and was found to be a confounder of the relationship between a participant meeting or exceeding a body core temperature of 38.0ºC (100.4ºF) and sex (Z=2.70, p=0.01). The significant two variable model suggested that with every 100 kilocalories of energy expenditure, a participant could be expected to have a 12 percent increased odds of their body core temperature reaching 38.0ºC, and if that participant was female, substantially increased odds of having a core temperature that exceeded 38.0ºC as compared to the men in this sample.

Figure 3. Gender differences in the duration of time T_c>38ºC by sex



Discussion

In this sample of agricultural workers, participant body core temperature exceeded 38ºC on 57% of the workdays examined, indicating that these workers, if working regularly, are at an increased risk for health effects related to their occupational heat exposure. Although the duration of time that these workers remained at or above the physiological limit varied widely, those participants who spent longer durations could be at an increased risk especially during peak work times when workdays are longer and work schedules encompass more days of the week. The identification of factors impacting the vulnerability of farmworkers to environmental heat stress is an important component in the path to the development of interventions to attenuate heat-related illness in this population. Being female and the level of energy expenditure in increments of 100 kcal during the workday were shown to impact whether a participant's body core temperature reached the physiological limit of 38.0ºC.

The generation of metabolic heat by increased energy expenditure should increase body core temperature per the principles of thermophysiology and metabolic heat, especially in the presence of environmental heat stress. The results from this analysis are in line with this expectation. This finding underscores the importance of further examining work-rest cycles when facing occupational heat exposure. Yet we know that workers do not have appropriate work-rest cycles and have no indications that they may be in danger. Intervention studies are needed to determine ways that workers can modify their work environments to protect their health.

Gender differences in heat stress response between men and women can be attributed to a variety of factors. According to the literature (14), increased levels of body fat could be a potential component as to why the women in this sample had a substantially higher odds of meeting or reaching 38.0ºC (14); however, the model was not able to show BMI, the primary measure for body composition in this study, as a significant predictor. Conversely, a large study of military recruits found BMI to predict heat-illness risk in male but not females and described aerobic fitness as a better predictor (15). Some issues with BMI include poor sensitivity and specificity for detecting obesity resulting in misclassification which may have introduced additional error when examining BMI as a predictor of T_c meeting or reaching 38.0 ºC (16). The incorporation of other measures of body composition like surface-to-mass ratio, body fat percentage, and body type morphology using more detailed anthropometrics utilized in other studies (14, 17, 18) may yield different results. Levels of respiratory fitness were not characterized in this study, which if examined, may have added additional justification for the gender differences in whether a participant's T_c reached or exceeded 38.0ºC as studies have shown that respiratory fitness may impact an individual's response to heat stress and levels of aerobic fitness (19). Additionally, hormone changes during different phases of the ovulatory cycle were not examined (20).

Strengths

Strengths of this pilot study included the innovative field-based approach to capture responses to heat stress in a farmworker population adding to the literature of regarding physiologic responses to heat stress in other populations. This study utilized sophisticated continuous monitoring of body core temperature and continuous actigraphy in a real-world work setting. Additionally, the repeated measures design added increased validity beyond a cross-sectional design and this study informs the development of future studies.

Limitations

The current study was a pilot study of a convenience sample of limited size and the population for this study was comprised of only one group of farmworkers: fernery workers, resulting in limited generalizability. Changes in the ActiGraph placement between the two seasons captured added additional error, and with body fat percentage for only one season, a proxy for body fat percentage, BMI, was utilized. We were unable to account for the impact of dehydration (19), a factor in body core temperature changes during exertion, and respiratory fitness. Environmental heat stress data were collected from a local weather network rather than at the worksite, precluding the incorporation of between worksite differences in the model.

Future Research

A larger study with a broader sampling of farmworkers across multiple sites and crop environments would provide increased validity and support the development of a model to not only examine the predictors for body core temperature meeting or exceeding 38.0ºC, but also to examine the predictors for achieving longer durations of a body core temperature that met or exceeded the threshold of 38ºC. Future, larger studies also need to examine a higher body core temperature threshold of 38.5ºC (101.3ºF) which is the physiological limit for acclimatized and medically selected workers (21) in addition to the 38.0ºC (100.4ºF) threshold. The workers in this sample reported working in agriculture for over a decade on average and had to have been working in a fernery for the last month to be eligible for participation in this study, indicating that these workers are likely acclimatized even though they haven't been medically examined or cleared by their employer for their specific work tasks. Further investigation into the time required to reach the T_c limits as well as the impact of the pattern of energy expenditure, including the timing and duration of rest breaks, can inform future interventions in this and other agricultural worker populations. Future studies will include dehydration measurements, a more comprehensive approach to body composition measurement, and microclimate measurements.

Conclusion

The results of this analysis indicate that a large proportion of fernery workers examined in this sample are reaching or exceeding the recommended limits of body core temperature, with female workers and those with increased energy expenditure having increased odds of this outcome, warranting further research in this and other farmworker populations. Inquiry in future, larger studies needs to include the duration of time spent above these threshold limits, time required to reach these threshold limits. A more expansive examination into factors placing individual workers at an increased risk for heat-related illness will further elucidate the results of this analysis. Findings from this analysis, and the future studies that this pilot study informs, contribute to the development of interventions to prevent heat-related illness in agricultural worker populations.

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INTEGRATIVE SUMMARY AND SYNTHESIS

Key Contributions

This feasibility study lays a foundation of work for informing the design and implementation of field-based biomonitoring studies of heat-related illness in farmworker populations. The key contributions of this work include the development of a conceptual framework to guide the design of field-based studies of heat-related illness (HRI) in farmworkers populations, the identification of feasible and best methods for characterizing factors related to the risk of HRI, and the provision of evidence that a substantial proportion of workers in a population of Florida fernery workers reach body core temperature levels during work that meet or exceed the recommended physiological limit for heat strain set by the American Conference of Government and Industrial Hygienists (ACGIH) (1). These findings prompt further research to characterize HRI in farmworker populations and the subsequent development of interventions to attenuate this occupational health risk. Findings from this work have already informed the design and implementation of The Girasoles Study (1R01OH010657-01), a study funded by the National Institute for Occupational Safety and Health (NIOSH).

Conceptual Framework Synthesis

The Farmworker Vulnerability to Heat Hazards Framework, inspired by frameworks conceptualizing the vulnerability of communities and systems to climate change (2-4), was developed in line with findings from the literature regarding heat illness and heat stress response predominately in non-farmworker populations. Future larger studies in a broader sample of farmworkers are needed to further validate this framework. Although still in development as more farmworker studies add to the current evidence, the current form of this framework sets a starting point for designing studies to examine HRI in farmworker populations, and identify those most at risk for HRI and to develop interventions upon modifiable factors.

Hazard

The hazard component of the framework, environmental heat stress, was captured in this pilot study using local meteorological data to estimate wet bulb globe temperature (WBGT). In addition to assessing the WBGT, the use of local meteorological data to capture and report the heat index (HI) is another option for characterizing the hazard component of this framework. The National Weather Service (NWS) calculates the Heat Index (5, 6) from meteorological data, which guides the issuance of heat warnings for communities and is an alternative to utilizing the WBGT, especially in those settings where the WBGT cannot be estimated.

Vulnerability Factors

Given that the intent of this pilot study was explorative with the specific intent of establishing population parameters for the variables being investigated, study findings encourage further research rather than changes to the framework. The vulnerability factors of this framework require further examination in future larger studies of broader farmworker populations.

Workplace Exposure. Results of the pilot study support the continued inclusion of workplace exposure as a component of vulnerability with work intensity, captured by workday energy expenditure in 100 kilocalorie units (kcal), being a significant predictor (OR=1.08, $CI_{.95}$ [1.005,1.15]) of a worker's body core temperature meeting or exceeding 100.4ºF (38.0ºC) (7). Although workday length was not found to be significant in the model, it remains an important component of the framework for further study and serves to quantify the dose of the hazard experienced by delineating the time spent at the worksite.

Sensitivity. Being female was the only component of sensitivity that was found to be a significant predictor in the model (OR=5.37, $CI_{.95}$ [1.03,18.30]), when adjusting for energy expenditure. The other sensitivity factors examined including of age, years working in agriculture, and body composition were not found to be significant predictors for the outcome examined, and need to be explored further in future studies. Findings of recent survey-based studies support the inclusion of years worked in agriculture and age under the sensitivity component (8).

Aerobic fitness was not examined in the current study and is challenging to quantify in field-based studies where there is already an extensive data collection protocol and lack of access to exercise monitoring facilities, but remains an important component in sensitivity according to the literature (9). All study participants reported having worked in a fernery for at least the last month and were considered to be acclimatized (10). Future studies should include other sociodemographic components, like the sleep recovery environment (11), as well as pre-existing medical conditions and medications.

Adaptive Capacity. Although beyond the scope of the current study, workplace hygiene factors including the distance of toileting facilities from the worksite have been shown to be associated with a higher odds of developing HRI symptoms (8). Different methods of dehydration assessment precluded the examination of hydration status as a predictor of a worker's temperature meeting or exceeding 38.0ºC and will be included in a future study. Limited data were collected regarding the clothing worn by participants. The use of plastic bags varied throughout the workday and often occurs sporadically per the presence of rain. Clothing adjustment factors could be used based upon the type of personal protective equipment worn, but plastic trash bags have not yet been evaluated (12). Analyzing clothing as a factor in heat-related illness of these workers was beyond the scope of this study and will require more extensive observational and reporting methods in future studies.

Heat Stress Response

The conceptualization of the heat stress response as resulting in physiologic equilibrium or disequilibrium for a worker was illustrated in Paper 1(13). The primary outcome measure of whether a worker's body core temperature met or exceeded 38.0ºC was chosen for the model in the pilot results analysis for this study which was derived from the duration of time that a worker's body core temperature exceeded 38.0ºC (7). With the use of this measure, evidence of the heat stress response was found with most workers meeting or exceeding 38.0ºC on at least one study day. The heat-related illness symptoms chosen for examination differed between 2012 and 2013 which precluded the examination of HRI symptoms as the key outcome variable in the model. Whether body core temperature exceeded 38.0ºC was chosen as the key outcome variable for the model over the Physiological Strain Index (PSI) because determining the proportion of workers reaching or exceeding the recommended physiological limit was a more meaningful initial finding for informing future studies than the PSI which is further explained in the feasibility findings below.

Feasibility and Best Methods

Recruitment, Population, and Setting

A primary aim of this work was to establish the feasibility of field-based biomonitoring of HRI in a vulnerable farmworker population (14). Through the partnership between Emory University and the Farmworkers Association of Florida (FWAF), forty-three fernery workers in Pierson, Florida were recruited through community ties and networks by community health workers, *promotores*. To participate in the study individuals had to be 18-54 years of age, currently working in a fernery for at least the last 14 days, of Latino descent, and able to speak English or Spanish. Individuals were not eligible for the study if they had a history of a disease of the esophagus, previous surgery of digestive tract, swallowing difficulties, had been diagnosed with diabetes mellitus type II, had been diagnosed with hypertension, were pregnant, or weighed less than 37 kilograms or 80 pounds. Participants were compensated with a $30 grocery gift care for each of the 3 study days plus an initial baseline visit. All study visits occurred at the FWAF office. Future studies should allow participants who have been diagnosed with diabetes mellitus type II or hypertension to participate as to not exclude these workers from assessment since there were a few workers deemed ineligible for this pilot study. Larger studies need to include workers with these pre-existing medical conditions to reduce bias in the population sample and to examine the potential impact of these factors. Future studies should include multiple locations across various types of agricultural work.

Environmental Temperature Monitoring

Due to the vulnerability of this working population, it was not a viable option to obtain direct wet bulb temperature (WBGT) readings in individual work environments of the participants. Instead publicly available weather information from a local monitoring station was successfully utilized. The workplace microclimate can deviate significantly from the general climate of a district, because direct solar radiation and wind speed play important roles in heat stress experienced by outdoor workers, and these could not be measured. Despite this limitation, publicly available information is recommended as an alternative when WBGT is not (15). Future studies should include assessment of workplace-based temperature monitoring for increased validity of environmental heat measurements.

Core Temperature Monitoring

The CorTemp® Wireless Core Body Temperature Monitoring system (HQInc., Palmetto, FL) consisted of an ingestible temperature sensor that transmits temperature readings from the gastrointestinal tract to a monitor that can be concealed under clothing, worn at the small of the back, and secured with a neoprene belt. Participants also wore a Polar® T31 non-coded transmitter (Polar Electro, Kempele, Finland) to capture coupled heart rate and core temperature readings for Physiological Strain Index (PSI) assessment (16). The use of this instrument required the participants to swallow a temperature sensor that is approximately the size of a large vitamin pill. In this feasibility study, farmworkers ingested the temperature sensor the evening before each of the study days due to early morning work start times. Monitors were worn during the workday and participants returned to the FWAF to remove study equipment for data downloading.

Thirty-second intervals for core temperature readings were selected for future studies because this was the shortest interval at which heart rate and core temperature could both be captured. Challenges with the core temperature monitoring protocol included pill passage before the workday. A goal of the feasibility pilot was to assess whether two days of core temperature monitoring data could be captured to allow for a repeated measures design. With the protocol that included administration of the core temperature pill after workday, even with the loss of data due to pill passage, data capture was deemed successful with nearly 90% of participants having core temperature and heart rate data on two study days.

Based upon the feasibility findings, an alternative protocol has been developed that is currently being used in The Girasoles Study. First, the temperature pill is sent home with participants after the workday to be taken at home with the evening meal to delay administration.

Then, if the participant passes the core temperature pill prior to the workday, a new pill is given at the pre-workday visit and the core temperature readings for early portion of the workday are truncated to allow for transit of the core temperature pill to the intestines. For studies where there is the availability of resources for the processing and data cleaning of large datasets (17), this approach is recommended.

Energy Exenditure Monitoring

The ActiGraph GTX3+ (ActiGraph, LLC, Pensacola, FL), was selected for use to capture energy expenditure to quantify work intensity over a device more geared towards sleep actigraphy. The raw counts and the body mass of the individual were translated into energy expenditure (EE) using the ActiLife 6 software package (ActiGraph, LLC, Pensacola, FL) (18). The placement of the ActiGraph monitor between 2012 and 2013 differed, with the waist placement adopted in 2013 because this placement is the typical placement in validation studies (19). Future studies capturing energy expenditure should utilize the waist placement for actigraphy monitoring since the wrist placement has not been validated.

Dehydration Assessment

Dehydration assessment was performed through the testing of three methods: body mass, urine specific gravity, and blood osmolality. A strength of the dehydration assessment in this study was the availability of serial measurements pre- and post-workday over the course of the three day study period. Body mass assessment was deemed as an insufficient method for assessing dehydration because input and output measurements could not be quantified during the workday. With this finding, urine specific gravity using an osmolality meter (Osmocheck®) (Vitech Scientific Ltd, West Sussex, UK) and blood osmolality using the i-STAT® Handheld Blood Analyzer (Abbott Laboratories, Abbott Park, Illinois) were added in 2013. Blood osmolality required blood sampling by fingerstick. Importantly, it was found that the use of microwaveable heat packs to warm the participants' fingers, that were often caloused from years of work in the ferneries, improve the ease and comfort of blood sampling. In this feasibility work, it was found that urine and blood osmolaity were weakly correlated at only some of the timepoints (pre-workday 2, post-workday 2, and pre-workday 3) with statistically significant correlations ranging from 0.51 (p=0.04) to 0.61(p=0.01). With these findings, future studies need to continue to investigate the agreement betweeen these hydration measures. Serial measurements of urine specific gravity and blood osmolality are the most feasible and valid methods for examinging dehydration in future studies.

Body Composition Assessment

Initially in this pilot study, body composition was examined using body mass index (BMI) only. Body fat percentage measurement via skinfold testing was added in 2013. Improvements to future studies entail the inclusion of BMI, body fat percentage measurement via skin fold testing and body circumference measurements and other versatile measures of body composition to capture a broader range of morphological factors to allow for the calculation of additional measures of body composition including categorization by body morphology type (20, 21).

Heat Stress Response Assessment

There was a change in the reporting heat-related illness (HRI) symptoms between the Summers of 2012 and 2013, due to the incorporation of the Occupational Heat-Related Illness Questionnaire, adapted from Fleischer et al. (2013) and the Pesticide Exposure in Female Farmworkers of Childbearing Age Survey (R21 OH009830), that precluded the examination of the factors predicting HRI symptoms. Although hot, dry skin has been incorporated as a HRI symptom in a few farmworker studies (22, 23), hot, dry skin is a symptom of late stage heat-related illness when an individual would be progressing towards heat stroke (24, 25) due to the high proportion of workers reporting hot, dry skin in this and another study (22), ahead of more moderate HRI symptoms including nausea or vomiting and dizziness, the hot, dry skin symptom reported may not be capturing what it was intended to originally capture. In future studies, hot, dry skin has been removed and instead, participants will be asked to report excessive sweating to capture the body's early compensatory efforts to cool itself (26). This alteration for the larger study can improve the validity of HRI symptoms being reported so that the pattern of occurrence for HRI symptoms in farmworker populations can be more accurately defined and compared to current HRI cascades and progression models.

Capturing the PSI has the advantage of incorporating the assessment of heart rate in addition to body core temperature, supporting a more comprehensive approach heat strain assessment. An advantage of the PSI is that remains applicable even when there is variability in personal characteristics, including hydration levels, sex, and clothing, making it unnecessary to know an individual's hydration status, sex or clothing ensemble to accurately differentiate levels of heat strain amongst individuals (16, 27, 28). Despite these advantages, PSI is a measure to express the level of physiologic strain at a given point in time, rather than a summary measure such as whether a participant's body core temperature met or exceeded the physiological threshold of 38.0ºC. Without established physiological limits for the PSI, it's utility as a summary measure for the risk of developing adverse effects from heat exposure is limited. Calculating the PSI may be more appropriate for performing functional analyses of heat strain occurring over the workday or during recovery times, which was beyond the scope of the current work. With the improved core temperature monitoring protocol as described above, PSI measurement becomes impractical in the field since measuring initial heart rate is necessary for PSI calculations. The combined use of self-reported HRI symptoms, the duration of time body core temperature exceeds the physiological threshold and the PSI would be ideal; however, issues with capturing initial heart rate precludes the inclusion of the PSI.

Evidence of Heat Stress Response in Florida Fernery Workers

The recently published 2016 NIOSH Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments (29) indicates that if multiple workers are surpassing the recommended physiological limits, then the worksite needs to intervene to make changes to decrease the risk of HRI in their workers. In this study, participant body core temperature reached or exceeded 38.0ºC (100.4ºF), the recommended physiological limit, on forty-nine (57%) of the workdays examined (n=86). On average, for those who met or exceeded 38.0ºC (100.4ºF), the duration of time was 79 minutes (SD=73, range=255) and the longest duration of time for meeting or exceeding the threshold was 285 minutes. Energy expenditure was found to be a significant predictor (OR=1.08 [1.005,1.15]) for the key outcome variable and once adjusting for energy expenditure being female was also a significant predictor (OR=5.37, $CI_{.95}$[1.03,18.30]).

These findings indicate that this sample of fernery workers are at increased risk for the development of HRI and warrant further research of HRI and the associated predictive factors in farmworker populations. In addition, these findings support the development of novel methods that use a combination of HRI symptoms and core body temperature to indicate when HRI is occurring.

Future Directions

The findings and limitations of the current study has informed the design of the Girasoles (Sunflower) Study (1R01OH010657-01), a large study of HRI in Farmworkers across multiple locations and crops in Florida through the partnership between Emory University and the Farmworker Association of Florida (FWAF), funded by the National Institute for Occupational Safety and Health (NIOSH). Similar recruitment methods continue in this study incorporating community ties with enrollment projections based upon this feasibility findings of the pilot study.

Protocol Improvements

The Girasoles Study is using the updated protocol that includes the option to administer the core temperature pill during the pre-workday visit to decrease data loss due to pill passage prior to the workday. A small pilot with cold weather controls is also currently underway to capture biomonitoring data in low-heat conditions for comparison in workers with hot-weather data. Because it has been hypothesized in the literature (11) that the recovery environment at home after the workday can affect an individual's sensitivity to heat the following workday, the Girasoles Study has incorporated evening/overnight home monitoring with the EL-USB-1 USB Temperature Data Logger (Lascar Electronics Ltd., Erie, PA) to measure ambient temperature and humidity in the bedroom. The Girasoles study is also piloting the use of the iButton (Maxim Integrated Products, Inc., San Jose, CA), which is a small personal temperature logger that can be worn attached participants' clothing to measure microclimate conditions at individual worksites via ambient temperature and humidity (30).

Conclusion

This work serves to build upon the foundations set by other investigators, assessing the feasibility of sophisticated core body temperature monitoring, dehydration assessment, actigraphy, and environmental monitoring along with acceptability feedback from workers to yield a more comprehensive approach to heat stress assessment in agricultural populations and providing initial data regarding the heat stress response, environmental heat, and related vulnerability factors. The findings of this study serve as evidence of the extent of the exposure burden for this vulnerable group as well as the feasibility of field-based biomonitoring studies in farmworker populations. Future, larger studies of HRI can build upon the findings of this study to further elucidate heat stress responses and related factors in farmworkers.

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