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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. The authors 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 nonobtrusive to their work, and that they were comfortable with study measures. Conclusions: These results open possibilities for characterizing HRI utilizing physiologic biomonitoring in vulnerable occupational groups.

KEYWORDS

Biomonitoring; farmworkers; heat-related illness

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 have a physiologic 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 deaths compared with 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 according to 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 physiologic effects of working in high temperatures has been conducted in controlled laboratory environments. Although surveys of US farmworkers document their perception of heat in their work environment and self-reported symptoms,[5–8] 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 physiologic 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 article describes the results of a pilot study to determine the feasibility of implementing a research protocol that includes field-based, physiologic 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;

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(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] According to the most recent climate data from the Florida Climate Data Center from 1981 to 2010, the normal maximum ambient temperature for Volusia County from May through August is 88.2°F (31.2°C).[11]

These temperatures, combined 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. *Promotores* selected by the leadership of 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, 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 to 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 <37 kg or 80 pounds.

Through the informed consent process, potential study participants were told what the study would entail and were asked to participate for 3 days of monitoring their usual work activity. All study explanations were provided in their native language. Participants were told in advance that they would be compensated $120.00 for the 3 consecutive days of monitoring and an enrollment (baseline) visit. After the baseline visit and 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 study visits, which might be on the way to the worksite for all participants and often 30 minutes from the homes of the participants. 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 three to five people each and testing took place over the course of 2.5 weeks in 2012 and 4 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 3 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 2 feet; therefore, if the belt holding the CorTemp data recorder were to fall down, the sensor could become out of range.

The Polar T31 noncoded 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 physiological strain index (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 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 physiologic 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, Pensacola, FL), an accelerometer that can measure triaxial accelerations from −3 g to +3 g, 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 ActiGraphs as well as downloading raw ActiGraph 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 did not draw the attention of supervisors or coworkers 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 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.

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 adult men and women are 3.7 and 2.7 L, respectively; however, some individuals may require more fluid intake owing 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 3 consecutive days. Participants were also asked 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, IL), which provides concentrations of sodium (Na), blood urea nitrogen (BUN), and glucose, from which values of plasma osmolality can be calculated using the following equation[22]:

$$\text{Osmolality} = 1.86\,\text{Na} + (\text{Glucose}/18) + (\text{BUN}/2.8) + 9$$

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, a point-of-care Osmolality Meter (Osmocheck) (Vitech Scientific, West Sussex, UK) was added 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

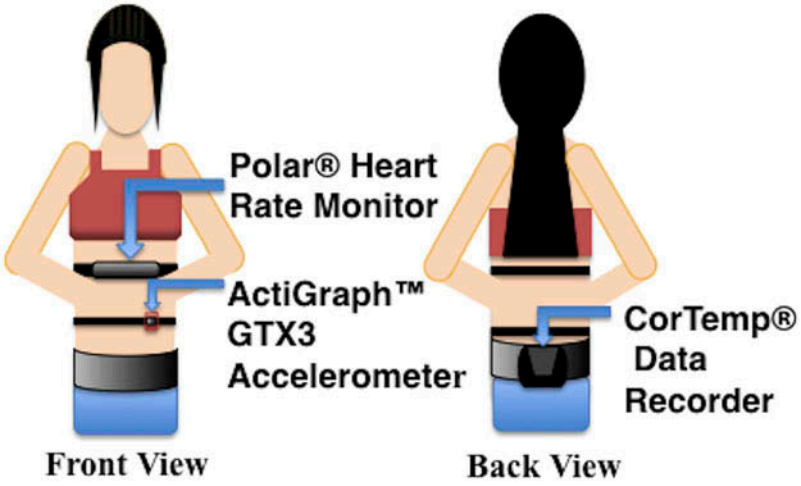

Figure 1. Placement of biomonitoring equipment utilized in summer 2013.

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 the following:

(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 benefited 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 and 2013, 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 physiologic 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.

The pilot study was designed to help determine how long it would take to enroll a projected goal of 20 participants each summer, based upon funding. Recruitment began 2 weeks before the testing periods, continuing throughout data collection. We found attrition to be minimal, even though it involved 3 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 3 days of testing.

Table 1. Descriptive characteristics of study participants, 2012–2013.

Characteristic	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)

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 was 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 challenge with using the CorTemp device is the variation in 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 1 and at the post-workday visit on workdays 1 and 2, 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, 3 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 2 days of workday temperature data. With a 3-workday collection protocol, the capture of 2 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 2 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 a portion of one workday period.

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, the 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 heat-related illness (HRI) biomonitoring, because they do not typically provide data that can be easily converted to energy expenditure. Additionally, the triaxial 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.

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. Measuring pre- and post-workday body mass presented logistical challenges. To collect body weight measurements, participants had to remove their work clothes down to undergarments and wear a gown.

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

Figure 2. Sample CorTemp raw data for one participant in 2013.

	Day 1	Day 2	Day 3
Start Time (self-reported)	07:40	07:40	08:00
Stop time (self-reported)	15:00	13:00	13:00
Total energy expenditure (EE) for workday (kcal)[1]	1906.5	1674.8	802.3
Average hourly EE (kcal)	260.1	314.2	160.5

Figure 3. Sample energy expenditure data for one participant in 2013.

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 on 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-workdays 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.

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.

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 noninterference 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, body mass index, and body composition that were collected over the study period to include as part of

	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

Figure 4. Sample dehydration assessment data for one participant in 2013.

"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."

Figure 5. Sample participant quotes from exit interviews.

their personal health record, along with worker-oriented educational materials providing guidance for preventing hear-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 physiologic 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 three *promotoras* and one nurse researcher involved. Workday data collection schedules preceded workday start times by a few hours, ranging from 4:00 AM to 7:30 AM. Participants returned to the FWAF office for post-workday visits as early as 10:00 AM and as late as 6:30 PM. 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, 3 days were required to capture 2 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.) 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 1 and at the post-workday visit on workdays 1 and 2 if the previously administered sensor had been excreted from the digestive tract.

According to the American Conference of Governmental Industrial Hygienists, the recommended core temperature limit for workers is 38.0°F (100.4°F).[23] In 2012, 13 out of the total 18 participants with core temperature data, exceeded the limit 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 recommended limit. In 2013, 17 out of the 22 participants with core temperature data exceeded the limit 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.

Lessons learned and next steps

Differing rates of passage of the intestinal temperature sensors created challenges. For instance, in some circumstances we only obtained 2 days of testing versus 3. Administering the sensor pill during the post-workday testing period was not an optimal practice for participants finishing work by 4 PM 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.[23–28] 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), which 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.[24] 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.[25] Plans for future studies include the use of the iButton (Maxim Integrated Products, 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).[26] We will be comparing these values with those collected by the Florida Automated Weather Network (FAWN). 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 only, supporting its continued use in future studies. This index is appropriate even when workers are wearing personal protective equipment or different clothing, because of its individualized nature, alleviating the need to adjust for clothing differences amongst individuals.[27] 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

Table 2. Proposed best measurement 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
Heat-related illness vulnerability factors	Occupational Heat-Related Illness Questionnaire[a]

[a]Adapted from Fleischer et al. (2013)[6].

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, which 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. This presents a possible bias in our sample. However, since no workers felt their jobs were endangered by participating 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 article were utilized in a pilot study during the summers of 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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References

1. World Health Organization. *Atlas of Heat and Climate*. Geneva, Switzerland: World Health Organization Press; 2012.
2. Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M, Hyatt O. Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts. *Annu Rev Public Health*. 2016;37:97–112.
3. Centers for Disease Control and Prevention. Heat-related deaths among crop workers—United States, 1992–2006. *MMWR Morb Mortal Wkly Rep*. 2008;57:649–653.
4. Arcury TA, Estrada JM, Quandt SA. Overcoming language and literacy barriers in safety and health training of agricultural workers. *J Agromedicine*. 2010;15:236–248.
5. Bethel JW, Harger R. Heat-related illness among Oregon farmworkers. *Int J Environ Res Public Health*. 2014;11:9273–9285.
6. Fleischer NL, Tiesman HM, Sumitani J, Mize T, Amarnath KK, Bayakly AR, Murphy MW. Public health impact of heat-related illness among migrant farmworkers. *Am J Prev Med*. 2013;44:199–206.
7. Flocks J, Vi Thien Mac V, Runkle J, Tovar-Aguilar JA, Economos J, McCauley LA. Female farmworkers' perceptions of heat-related illness and pregnancy health. *J Agromedicine*. 2013;18:350–358.
8. Spector JT, Krenz J, Blank KN, Blank KN. Risk factors for heat-related illness in Washington Crop Workers. *J Agromedicine*. 2015;20:349–359.
9. Internal Revenue Code of 1954, 26 U.S.C. 3121(g).
10. Zierden DF, Griffin M. *Humidity in Florida*. Tallahassee, FL: Florida Climate Center; 2014. Available at: http://climatecenter.fsu.edu/topics/humidit. Updated April 29, 2014. Accessed September 2, 2015.
11. Florida Climate Center. 1982–2010 Normals: Daytona Beach. Available at: http://climatecenter.fsu.edu/products-services/data/1981-2010-normals/daytona-beach. Accessed September 2, 2015.

12. Casa DJ, Becker SM, Ganio MS, Brown CM, Yeargin SW, Roti MW, Siegler J, Blowers JA, Glaviano NR, Huggins RA, Armstrong LE, Maresh CM. Validity of devices that assess body temperature during outdoor exercise in the heat. *J Athl Train*. 2007;42:333–342.
13. Moran DS, Shitzer A, Pandolf KB. A physiological strain index to evaluate heat stress. *Am J Physiol Regul Integr Comp Physiol*. 1998;275:129–134.
14. Brotherhood JR. Heat stress and strain in exercise and sport. *J Sci Med Sport*. 2008;11:6–19.
15. Montain SJ, Sawka MN, Cadarette BS, Quigley MD, McKay JM. Physiological tolerance to uncompensable heat stress: effects of exercise intensity, protective clothing, and climate. *J Appl Physiol*. 1994;77:216–222.
16. John D, Freedson P. ActiGraph and Actical physical activity monitors: a peek under the hood. *Med Sci Sports Exerc*. 2012;44(1 Suppl 1):S86–S89.
17. ActiGraph. What is the difference among the Energy Expenditure Algorithms? Available at: https://help.theactigraph.com/entries/20744123-What-is-the-difference-among-the-Energy-Expenditure-Algorithms-. Published 2011. Accessed 2012 July 1, 2012.
18. Sasaki JE, John D, Freedson PS. Validation and comparison of ActiGraph activity monitors. *J Sci Med Sport*. 2011;14:411–416.
19. Williams R. Kcal estimates from activity counts using the Potential Energy Method [abstract]. Pensacola, FL: CSA, Inc., ActiGraph; 1998. Available at: http://actigraphcorp.com/research-database/kcal-estimates-from-activity-counts-using-the-potential-energy-method/ Accessed September 2, 2015.
20. Sawka MN, Cheuvront SN, Carter R 3rd. Human water needs. *Nutr Rev*. 2005; 63 (6 Pt 2): S30–S39.
21. Cheuvront SN, Ely BR, Kenefick RW, Sawka MN. Biological variation and diagnostic accuracy of dehydration assessment markers. *Am J Clin Nutr*. 2010;92:565–573.
22. Dorwart WV, Chalmers L. Comparison of methods for calculating serum osmolality form chemical concentrations, and the prognostic value of such calculations. *Clin Chem*. 1975;21:190–194.
23. American Conference of Governmental Industrial Hygienists (ACGIH). *Heat Stress and Strain: TLV® Physical Agents 7th Edition Documentation*. Cincinnati, OH: ACGIH; 2009.
24. Bernard TE, Barrow CA. Empirical approach to outdoor WBGT from meteorological data and performance of two different instrument designs. *Ind Health*. 2013;51:79–85.
25. Cecchini M, Colantoni A, Massantini R, Monarca D. Estimation of the risks of thermal stress due to the microclimate for manual fruit and vegetable harvesters in central Italy. *J Agric Saf Health*. 2010;16:141–159.
26. Hubbart J, Link T, Campbell C, Cobos D. Evaluation of a low-cost temperature measurement system for environmental applications. *Hydrol Process*. 2005;19:1517–1523.
27. Moran DS. Stress evaluation by the physiological strain index (PSI). *J Basic Clin Physiol Pharmacol*. 2000;11:403–423.
28. International Organization for Standardization (ISO). *ISO 7243: Hot Environments—Estimation of the Heat Stress on Working Man, Based on the WBGT-Index (Wet Bulb Globe Temperature)*. Geneva, Switzerland: ISO;1989.