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Recruitment, Methods and Descriptive Results of a Physiologic Assessment of Latino Farmworkers: the California Heat Illness Prevention Study (CHIPS)

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Abstract

Objective—The California Heat Illness Prevention Study devised methodology and collected physiological data to assess Heat Related Illness (HRI) risk in Latino farmworkers.

Methods—Bilingual researchers monitored HRI across a work shift, recording core temperature, work rate (METs) and heart rate at minute intervals. Hydration status was assessed by changes in weight and blood osmolality. Personal data loggers and a weather station measured exposure to heat. Interviewer administered questionnaires were used to collect demographic and occupational information.

Results—California farmworkers (n=588) were assessed. Acceptable quality data were obtained from 80% of participants (core temperature) to 100% of participants (weight change). Workers

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◦ Supplemental Digit Content 1. Image of recruitment poster for participant enrollment. Pdf
◦ Supplemental Digit Content 2. Image of the equipment used on the participants. Pdf

(8.3%) experienced a core body temperature ≥ 38.5°C and 10.8% experienced dehydration (lost more than 1.5% of body weight).

Conclusions—Methodology is presented for the first comprehensive physiological assessment of HRI risk in California farmworkers.

Keywords

Heat-related illness; Farm work; Immigrant Latino workers; Physiological testing; Core temperatures; Hydration; Occupational heat exposure

Introduction

Deaths from Heat Related Illness (HRI) are preventable, but on average, 688 individuals in the USA have died of HRI each year since the beginning of the 21st century (1). Deaths attributed to occupational HRI among USA crop workers average 28 per year; 20 times the rate for all U.S. civilian workers (2). Both mortality and morbidity from HRI are likely to be greatly underestimated (3) because HRI outcomes are often non-specific or are designated ‘contributory’ rather than as the underlying cause (4). HRI poses a major health risk for California farmworkers, estimated to number over half a million in 2014 (5). The California Occupational Safety and Health Administration (Cal-OSHA) has launched informational and regulatory programs to reduce HRI among farmworkers since 2008 (6, 7) and conducts enforcement activities throughout the summer season. With climate change, increasing exposure to elevated summertime heat is expected (8). California has seen a steady increase in summer mean temperatures since 1985 (9). The projected increases in temperature will severely impact the inland valleys, the major agricultural areas in California, where the vast majority of farmworkers are employed (10).

Current HRI regulation is based on physiological data collected from military settings and athletes, with limited applicability to agricultural work conditions (11). Alert levels (when to implement protective actions such as mandatory rest periods) are based on exposure using the Heat Index (12) and do not include work intensity, individual susceptibility or whether the work is in sun or shade, which vary greatly across farming task and crop type. Studies investigating the risk of heat illness in USA farmworker populations have almost exclusively relied on questionnaires or focus groups conducted at labor camps or community sites (13-17). Interviews conducted at the work site may influence results due to potential opposition of employers. Unfortunately, current instruments do not capture objective physiological data from monitoring at the worksite.

Ninety-two percent of farmworkers in California identify as Latino (18), and only 14% were born in the USA [ACS, 2012]. The number of farmworkers in California is hard to establish because of many factors including immigration status, migration between growing areas, seasonal or part time work and language barriers. The estimate for the number of California farmworkers was 415,000 full time equivalents (FTE) in 2014 (about one third of the total in the USA) (5). However, approximately two farmworkers make up one FTE; therefore, a best estimate of 829,000 unique workers were hired in 2014. Between one-third and 2/3 of farmworkers are thought to be unauthorized (5). For the same reasons that immigrant farmworkers are hard to enumerate, they often present a variety of methodological and cultural challenges that reduce their participation in physiological and epidemiological studies (19). Because of their immigration status, they are likely to have a distrust of government and anyone related with government (including researchers) and are reluctant to participate in studies that would require revealing personal information (20, 21).

The California Heat Illness Prevention Study (22) is aimed at collecting accurate objective data on the physiological responses of California farmworkers to heat. A large-scale data collection was needed because of the wide variation of work conditions and intensities, and the diversity of environments in the state. Such a large-scale field study of biological parameters for normal farmworker activity has never been conducted and presents unique challenges. The methods developed to assess risk of HRI in immigrant Latino farmworkers are described in this paper.

Methods

Physiological data were collected over the course of one workday from Latino farmworkers throughout California. The study took place in the summer growing and harvest seasons (June to October) of 2014 and 2015. As this paper is the first to use the combination of physiological assessments in this immigrant Latino farmworker population, the methods are described in detail. The [Blinded by request from JOEM] Institutional Review Board approved the study participant procedures.

Participation: Recruitment of Farms and Farmworkers

A convenience sample of Latino farmworkers was enrolled for this cross-sectional study by recruiting through California farms and farm labor contractors (FLCs). The first step was to gain approval from the employers, which was done through a combination of outreach activities, culminating with individual phone calls. The contacts were initiated by University of California (UC) cooperative extension specialists (nearly every county in California has an extension office), suggestions from the National Institute of Occupational Safety and Health (NIOSH) Western Center for Agricultural Health and Safety (WCAHS) faculty and staff, and meetings with farmers or FLC at conventions or other gatherings. The research study was also advertised at “train the trainer” events on Heat Illness Prevention (conducted by the WCAHS educational and outreach specialist) and at the UC Integrated Pesticide Management “train the trainer” certification workshops throughout the state.

Recruitment Criteria

INCLUSION:	EXCLUSION:
• Male or female farmworker, carrying out normal field worker tasks; may include supervisors	• Under age 18.
• Work outdoors in the fields / open packing space for a full shift (could vary from 5-12 hours).	• Work less than a full shift (generally under 6 hours) or working in an air-conditioned cab / environment
• Latino/a ethnicity (self-defined), may speak Spanish or English, but literacy (reading or writing) not required	• Unable to understand and answer questions in Spanish
	• If female - pregnant

INCLUSION:	EXCLUSION:
• May include nursery workers who work outside exclusively or landscapers in rural setting	• Unable to swallow large pills (specifically the sensor)
• Normal body temperature at start of shift (use of tympanic ear thermometer)	• Pre-shift temperature ° 37.5°C or immediate/current gastrointestinal upset (vomiting or diarrhea)
• Work does not involve extensive driving or frequent use of an ATV, which study observers would be unable to follow	• Have an implanted electro-medical device such as a pacemaker or recent stomach surgery

The second step was to recruit individual participants from the contacts made with farms and FLCs. An attempt was made to recruit all of the eligible workers at a farm or on an FLC team. A study field team of graduate and undergraduate students, all of whom were bilingual and bicultural, presented the study to workers the day before the field study began. The recruitment visit was scheduled with the cooperation of the worksite supervisor or *mayordomo*, and occurred before the work day started or during a rest or lunch break. A poster with depictions of the study equipment and what would be required of participants for their one day enrollment was used as part of a verbal presentation of the research aims (see image, Supplemental Digital Content 1, the recruitment poster for participant enrollment). Examples of the ingestible thermal sensors (heat pills) and other equipment were passed around or worn by the research team at the demonstration. Farmworkers were individually recruited using a consent form and informed of their rights as study participants. All recruits were willing volunteers; it was emphasized on several occasions in the presentation and recruitment that they did not have to participate, did not have to answer specific questions if they did not wish to do so and could withdraw at any time.

The study team organized recruited workers into participation groups of up to eight individuals per day (the maximum number of equipment sets) and set up a schedule with the assistance of the supervisor. Scheduling was flexible to encourage participation. For example, a carpool could participate on the same day, and accommodations were made for expected absences or workers moving to different areas or farms. For a complete one-day participation in the study, the volunteers were given a $50 gift card. The compensation was for time and effort expended. Each participant was required to arrive 30 minutes earlier than normal and stay at least 40 minutes after their shift while they completed the study procedures. As many of the farmworkers had less than the equivalent of a sixth grade education, they were not expected to read or fill in questionnaires, rather the information was gathered through an interview. Data collection ranged from 1 to 5 days at any one location depending on the success of recruitment and the size of the work force.

Physiologic Data Collection

As farmworkers arrived in the morning, they were welcomed by a study team member and accompanied to each research station. The criteria for study participation were reviewed with each individual before they were given the heat pill. Participants were weighed in after removing their outer layers of clothing and footwear, leaving only a base layer over underwear. In addition, their height was measured without shoes using a Seca™ model 213 stadiometer [Seca GMBH & CO., Hamburg, Germany]. A pre-shift questionnaire was administered, blood drawn, and body temperature, work measuring, and ambient heat exposure instruments attached (see below). The order of pre-shift assessments depended on the availability of each station. The worker was photographed (with their face obscured) to establish their clothing. The post-shift measures were similar except that measurement of height was omitted. In the afternoon, participants were not offered a cool beverage until they had been weighed.

Body Temperature and Work

Core body temperature is a product of the sum of external heat load plus the internal metabolic heat load (including work) minus evaporative heat loss due to sweating. Core body temperature was measured using CorTemp ™ HT 15002 ingestible wireless thermistor transmitters [CorTemp HTI Technologies, St. Palmetto, FL], i.e., a ‘heat pill.’ The 10-mm long sensor transmits core temperatures at 1-minute intervals as it moves through the gastrointestinal tract (normally 20 to 36 hours) and is not recovered. The signal is picked up by a small recorder (about the size of a pack of cards) placed in a pouch worn on a waist-belt close to the spine. The manufacturer’s reported accuracy of the sensor is ± 0.1 °C. Each heat pill was pre-calibrated against a thermocouple in a sterile water bath to ensure the heat pill was stabilized at the designated temperature. A systematic bias has been reported, with the sensor reading higher by 0.07 °C to 0.15 °C (acceptable bias was set at 0.1 °C, suggesting that calibration allows adjustment of ‘raw’ core temperatures using linear regression techniques) (23). The heart rate (surrogate for workload) was recorded simultaneously using a Polar T31 ECG transmitter fitted around the chest (a variant of the Holter cardiac monitor). Adjustments were made to assure secure fit and comfort. All equipment that touched the skin was thoroughly sanitized between uses.

Because heart rate may be impacted by heat strain, an accelerometer (Actical™ Philips Respironics, Murrysville PA) was used to measure work rate independent of the effect of metabolic heat load. The accelerometer measures energy expenditure, which can be converted to METs (Metabolic Equivalents)(24). The accelerometer was firmly attached to the waist belt at the iliac crest of the hip using both a Velcro™ band through the mounting tabs and zip ties to ensure it remained in place during rough field work. (See image, Supplemental Digital Content 2, the equipment and position used on the participants.)

Hydration

In-field estimation of hydration is limited by lack of facilities available for laboratory studies. Therefore, two methods of estimating hydration were employed: change in body weight and plasma osmolality (measures plasma concentrations of solutes). Most farms have portable toilets, which are set up daily at the field location, but the number of workers per unit is large, interior space limited and hygiene (hand washing) limited to exterior portable sinks. For cultural and practical reasons, urine collection, including urine volumes, specific gravity or color, are difficult to collect and were not chosen as a measure of hydration in this study. Change of weight was selected as the most acceptable, although crude, measurement of hydration status change. This has been demonstrated to be an accurate way to measure hydration status in field settings (25). Weight was measured (twice at each time point) on a scale placed on a leveled board, pre- and post-shift, using a Seca™ Model 874 scale (Seca

GMBH & CO.). Workers were asked to remove their outer layers of clothing and footwear, leaving only a base layer over underwear. This process was repeated after they ceased work for the day. A particular effort was made to ensure all items were taken out of pockets, and that the same clothing was worn in the post-shift weighing. Participants were not asked to empty their bladder or completely strip before being weighed due to time and social norms / compliancy constraints. When the participants were checked-in at the post shift site, they left any beverages where they would pick up their incentive, and were offered cold bottled water only after they had been weighed. (The first item of the post-shift, after equipment removal, to be completed)

A second measure of hydration available to this field study was an assessment of solutes in plasm expressed as milliosmoles per Kg of water (mOsm). As the body becomes dehydrated, the solutes become more concentrated, and the osmolality rises. An i-STAT™ portable handheld analyzer (battery operated)(Abbot Point of Care Inc., Princeton NJ) and chem8+ panels were used to measure the components of blood (sodium, potassium, glucose, blood urea nitrogen) and to assess pre-shift hydration status. Approximately 95 μL of capillary blood was obtained as 3-5 drops from a finger stick using a lancet to one of the ring fingers. The procedure described by Dowell et al (26) was followed, using hand warmers in the cool pre-shift. The assessment was repeated at the post-shift monitoring, although no hand warmers were used. Analyses were conducted inside a diesel-powered car to ensure an optimum ambient temperature range for the analyzer (between 16 and 30 °C) and to exclude dust or other potentially interfering material. Serum osmolality was calculated with the Wallach equation (27). Self-reported water and other beverages consumed during the workday were recorded by trained interviewers.

Exposure Data

An inventory of weather data published on the Internet from the nearest local irrigation district and airport for each location was made. In recognition of environmental microclimates, ambient temperature was measured at minute intervals in several ways:

1) A general measure of weather conditions, comparable to airport or California irrigation district data collections, was made using a HOBO U30 weather station on a 3-meter tripod (Onset Computer Corp Bourne, MA). Ambient conditions were recorded at a stationary central location at each farm on each day of monitoring.

2) A mobile measure of the local field conditions where participants were working (which could change more than once per day) was made using a QUESTemp 36 thermal environment monitor on a 1.2-meter tripod (Quest Technologies, Inc., Oconomowoc, WI).

3) A personal measure of ambient heat exposure was made by having each worker wear a personal environmental data logger or ‘heat pen’ (Lascar EL-USB-2-Lascar Electronics, Erie, PA); this device measures temperature, relative humidity and dew point and records them at minute intervals. The data logger was placed in a sleeve and attached to the outer surface clothing of the workers using a lanyard and clip. Workers were instructed to move the data logger, if needed, to a place on the torso where it would not interfere with their work and to make sure it was not covered by

clothing. The study team observed participants throughout the day at the worksite, and the vast majority of the workers were compliant. However we were not able to interfere with the regular work, and would wait for a work break to remind any worker of the correct positioning of any equipment. All of the temperature transducers were pre-calibrated together in an oven against a thermocouple at two different temperatures (26 and 42 °C) on a weekly basis.

Assessments and Statistical Analyses

All statistical analyses were conducted using SAS 9.4 (SAS Institute, Inc., Cary, NC).

The following analyses were conducted to determine whether the physiological protocols were feasible and acceptable in this immigrant farmworker population:

- A comparison of the CHIPS sample with the National Agricultural Workers Survey (NAWS)(28) to assess whether the CHIPS recruitment methods provided a reasonably representative cross-section of Latino farmworkers in California. Proc SurveyReg was used to compare continuous variables, e.g., age and years in agriculture, while Proc SurveyFreq was employed for categorical variables. Both procedures adjust for differing population strata, clusters and weights. The level of significance for all comparisons was set at $\alpha = 0.05$.
- An accounting of the yield of physiological data collected (percentage of useable data) to indicate the acceptability and reliability of the instruments used for this type of field study.
- The distribution of physiologic and personal environmental data collected from CHIPS participants were displayed using the schematic option for Box Plots in SAS, with the 'whiskers' set at 1.5 Inter-Quartile Range (IQR) and circles indicating outliers. Measurements collected at one-minute intervals included core temperature, heart rate, accelerometer activity and personal environmental exposure to heat and relative humidity. Post- minus pre-shift differences in blood osmolality and the across-shift change in weight (%) were also calculated. The maxima and minima were calculated from consecutive 3-minute moving averages for all the electronic data.
- We used the following criteria to assess the risk of HRI:

  Core temperature > 38.5 °C for at least one minute and / or heart rate > [180 - (age in years)] for 5 consecutive minutes (29).

  Dehydration defined by either a weight decrease > 1.5%(29), or by osmolality > 295 mOsm (30).

Results

Recruitment

Workers (n=588) were recruited on 30 farms over two summers from two major crop-growing regions of California: the Central Valley in the region adjacent to Mexico and the Imperial Valley. Enrollment was estimated to be close to 50% of those to whom the study was presented. With limited time available, the study team was unable to make a complete head count; also, potential recruits arrived and left during the recruitment talk. In addition, after the first day of monitoring, new workers often asked to enroll. They may or may not have been at the original presentation. Each participant was given a full explanation (repeating the presentation talk) and was individually consented. A more common problem was non-appearance of potential participants. Frequently, workers would be scheduled away from the study site to another location or even at a different farm, would not come to work, or could not make it to work early enough to both participate and start work on time.

The farming operations grew a wide range of commodities including low-growing field crops, such as squash, peppers, tomatoes, melons, cucumber, sweet potatoes and strawberries; other field crops, such as sunflowers, corn, onions, cherry tomatoes and grapes; and orchard or covered crops, such as pistachios, almonds, berries, peaches, prunes, nectarines and olives. Coastal valleys, where lettuce and salad crops are grown, were not included in the study because high heat days are less predictable there.

Comparison of CHIPS Population with the National Agricultural Workers Survey (NAWS)

The NAWS is an employment-based, random sampling of crop workers throughout the USA (28) in which the country is split into six regions, and California is a single sampling region. Data were collected over three cycles in each fiscal year using a probability sample of crop workers and multi-stage sampling. The farmworkers are interviewed at their workplaces and, therefore, only employed workers are surveyed. Both migrant and seasonal crop workers are interviewed. A comparison was made between selected demographic and work characteristics of CHIPS participants (Table 1) from 2014-5 with the same cycle period (summer) of the latest available NAWS data (2013-2014).

Although CHIPS was a convenience sample, the demographic characteristics of the sample were similar to the latest data available from the California section of the NAWS. CHIPS recruited Latino workers and so enrolled a higher percentage of participants who identified as Latino (99% vs. 96%, $p = 0.009$), but both samples were overwhelmingly Latino. [Subsequently, on the day of participation, four workers identified more strongly with non-Latino ethnicity.]The CHIPS workers, if they had immigrated, were resident in the USA for fewer years than the NAWS sample (15.5 vs. 19.3, respectively, $p = 0.006$) and the family income was likely to be lower ($p = 0.0009$).

Data Collection

Acceptability of Procedures and Equipment—After having inspected the heat pill at recruitment, very few enrolled workers (less than five over two years) were unable to swallow the pill. The chest strap (three sizes) for the heart rate monitor was uncomfortable for some participants, usually those of larger body size. Female participants used a six-foot high folding screen for privacy, and female team members assisted them to make sure the fit was snug but not too tight. Males were given the same opportunity, but rarely used it. A few of the participants had trouble with blood collection; less than five quit the study because they were uncomfortable with the procedure. A second sample was occasionally collected if the analyzer did not function correctly.

Data Collection Yields and Quality—The yields from the equipment worn or measured from the participants conducting a normal day of farm work were acceptable (Table 2).

Core Body Temperature—Eight heat pills (1.4%) failed during the shift or were eliminated by the worker during the shift. For the first one to three hours after ingestion, the heat pill remains in the stomach (31, 32), and the temperature recorded at that time is not reliable. Once the pill enters the intestine, it may still be affected by cold drinks that result in sharp temperature drops of 2 °C or more (33). Here, examples are given of core temperatures in participants without these drink ‘dips’ and one with multiple such dips (Figure 1 a, b). After cleaning of the data (removal of non-physiological temperatures and recoveries), there were sufficient data to determine the physiological maximal and minimal core temperatures for about 80% of the sample.

Heart Rate—Data could not be retrieved from four of the heart rate recorders, and after cleaning of the data, 84.3% of the files were assessed as being of sufficient quality for modeling purposes. Figure 1c demonstrates one participant’s heart rate trace and smoothed values. Figure 1d is from a participant for whom there was considerable interference in the signal, most likely due to another study participant in close proximity. In combination, 74% of the participant data files had both sufficient quality core temperature and heart rate traces.

Work Rate, Personal Heat Exposure (Heat Pens) and Hydration—A total of 13 sets of data were irretrievable from the accelerometers, with two accelerometers lost in the field. All of the remaining data were of sufficient quality for analysis. The heat pens were subject to battery failure, device error, damage, and one was lost in the field; 31 did not yield data, but 93.7% of all data sets were of good quality. Assessment of blood for osmolality had a higher failure rate pre-shift when there was less time available to work with participants as well as participants having lower peripheral blood flow. Almost 95% of the participants were assessed for their osmolality status across the shift.

Physiological Measurements and Heat Exposures

Maxima of Physiological and Environmental Measurements—Figure 2a-f displays the ranges of maximal physiological values experienced by the participants. Figure 2e shows the distribution of osmolality at the pre-shift assessment. In Figure 2a, the maximum core temperature recorded (calculated from the three-minute moving average) was just under 40 °C (104 °F). The mean of the moving averages for heart rate (Figure 2b) was 134 beats per minute (bpm), which would not be classed as high exertion even for extended periods in a middle-aged or younger worker. The ‘heat pens’ attached to the outer layer of clothing record both temperature and relative humidity. Because the sleeved heat pen is held close to the body, but on top of the outer layer of clothing, an assumption was made that this measurement is affected by heat energy conducted from the body and sweat as well as a portion of the radiant and convective heat from the environment, Personal Heat Exposure (PHE)(Figure 2c). The most extreme value measured was 45 °C (113 °F). By way of comparison, the weather station located in the same field as the workers (QUESTemp 36) recorded the Wet Globe Bulb Temperature (WBGT) for the environmental heat exposure with a lower maximum of 36.5 °C (Figure 2f). Maximal activity measured in MET averaged over three consecutive minutes (Figure 2d) was in a narrow band averaging 3.4 MET. The vast majority of the farmworkers were euhydrated at the start of their work shift, with only 2% having a morning mOsm > 295 (Figure 2e).

Range (Maximum - Minimum) of Physiological and Environmental Measurements—Figure 3a-f displays the cross shift changes in physiological and weather conditions. Across the shift, the mean change in core body temperature (Figure 3a) was + 1.0 °C and the maximum difference was + 2.6 °C. The mean difference between maximal and minimal heart rate (Figure 3b) was 63 bpm. However, the change in personal exposure to heat (PHE, Figure 3c) varied widely, with the largest individual range being 29 °C. In contrast, the stationary measure of WBGT recorded a maximum daily difference of just over 20 °C, indicative of summers in a dry, desert-like climate. Over the shift, blood osmolality increased in just over 60% of the participants, and the median change was + 1.35 mOsm (Figure 3e). At the end of the work shift 6% would be classed as dehydrated by this criterion. As would be expected, a large proportion of the workers lost water weight (Figure 3d), with 433/587 participants (73.8%) losing weight, and 11.8% classed as dehydrated having lost > 1.5% of their morning weight.

Discussion

Physiological studies of heat strain using an ingestible sensor have been conducted on workers from many different occupations, such as coal mining, sports and fire-fighting (34-38), but not on farmworkers. The CHIPS study is the first to conduct comprehensive physiological monitoring of heat strain in Latino farmworkers in the USA. A pilot study of 100 farmworkers was conducted in 2012, and the results were used to develop and refine the methods used in this manuscript (22). Data from the summer 2014 CHIPS study was also used to determine acute kidney injury prevalence in this population (39). While the farms in this study were not randomly selected because access to the workers required employer cooperation, the study demographics were similar to the population-based sampling conducted by NAWS in 2013-2014. Thus, CHIPS results are likely to be representative of Latino farmworkers in California.

Recruitment was maximized by having a research team of similar ethnicity and cultural background as the participants and both visual and verbal presentations with no expectation of participant literacy. The effect of the study on the workday was minimized by conducting procedures before and after work. Worker participation was increased by accommodating carpools, anticipating expected and unexpected absences, and including workers who had been absent on the recruitment day or wished to participate after first declining. In addition to the farmer, farm manager or labor contractor, the cooperation of the immediate site supervisors or *mayordormos* was essential.

Use of Ingested Sensors in Farmworkers

Rectal thermometers are considered the gold standard for measuring internal temperature (40). However, other than for laboratory or short monitoring periods, rectal thermometers are not acceptable in field situations. Other commonly used methods for measuring body temperature include oral, axillary, aural or temporal/forehead thermometers, all of which differ considerably from the gold standard and are not useable as a measure of core temperature (31). A few studies have included outdoor exercise to examine the use of ingestible sensors to assess their accuracy and reliability when compared to rectal thermometers, but studies have not been done in an occupational environment (31, 41, 42). A review of 12 comparisons (43) indicated good agreement between the ingestible sensor and rectal thermometer. The pooled estimate was that the intestinal sensor differed by < ± 0.4 °C from the rectal thermometer for 10 of the studies. Most individual studies found a bias toward slightly higher temperatures with the intestinal sensor. The Health Hazard Evaluation unit at NIOSH has used ingestible sensors in industrial sectors, but not in the agricultural setting (35, 44, 45). This study demonstrates that heat pills are a valuable and viable means of estimating the core temperature of farmworkers while performing a variety of normal tasks. However, there are limitations for their use and the type of data that can be analyzed.

The American Conference of Governmental Industrial Hygienists (ACGIH) indicates that a core body temperature above 38.5 °C (101.3 °F) puts an individual at risk of HRI; 8.3% of the participants in this study with sufficient data were at or above this criterion. This is a lower percentage than a study of heat strain in aluminum smelter workers (29%) (46) or firefighters wearing personal protective gear (>68%) (35), but there are no data with respect to what is a 'normal range' in US farmworkers. One measure of heat strain is to have sustained a heart rate [180 – (age in years)] bpm for five minutes or more (29). This criterion was reached by 18.0% of our sample for whom there were sufficient data. Just under 3.5% of our population attained both measures of heat strain.

Limitations of the Heat Pill in Farmworkers

Participants were not resistant to swallowing the sensor. The main limitation to using an intestinal sensor in field studies is that drinking volumes of cold water frequently interfere with the assessment of core temperature if the sensor is ingested less than 6-10 hours before monitoring (32, 41). Ideally, the sensor should be ingested the night before the study. Pilot testing in the study population indicated that less than half of the workers remembered to take the heat pill before bed (despite telephone reminders), and many lost the sensor before it could be ingested. Asking the participants to swallow the heat pill while still at work the day before monitoring would have required more time and cooperation from the farm supervisors than was available. Also, a proportion of the sensors would be eliminated before the end of the monitoring shift; 20% or more of fit and active people will pass the pill within 12 hours of ingestion (47). Therefore, the heat pill was administered at the pre-shift, directly after the study team established that all study criteria and safety conditions were met, and before any other pre-shift measures were conducted. Because farm workers were encouraged to drink *ad libitum*, approximately 85% of them had at least one core temperature dip attributable to a cold drink. Up to 20% of the recordings were determined to be unusable. However, if the temperature reductions were confined to the early part of the work day, then the artificially lowered temperatures were removed so as not to record non-physiologic minima.

Estimation of Work Intensity and Exposure to Environmental Heat

Doubly labelled water is the gold standard for measuring energy expenditure, but is impractical for field studies (48). Here, work intensity was estimated using two measures simultaneously: heart rate monitors and accelerometers. Accelerometer data, unlike heart rate (which can be biased high by thermal responses to high ambient temperature), clearly indicate rest periods and allow estimation of both maximal and average or total energy expenditure over the course of the work shift. Accelerometers have been used extensively in studies as they are non-invasive, of negligible weight and size, reliable, and an objective means of estimating physical activity (48). The minimum MET value (resting, indicating just baseline metabolic activity) is set at 1. Commonly, MET are classified as sedentary (1 up to 2), light (2 to less than 3), moderate (3 to less than 6) and vigorous (6 or more)(49, 50). In this population, the mean maximum was just in the moderate range, and only a very small proportion had maxima in the vigorous range. However, the Actical ™, as with other accelerometers, is thought to underestimate time spent in vigorous activity and overestimate time walking or in sedentary activities when using the common regression equations to predict energy expenditure (51). In comparison, heart rate responds both to the intensity of work and to higher body temperature (52); therefore, the combination of heart rate and accelerometry allows estimation of the differential effect of metabolic work and increasing environmental temperature on core body temperature. Measures of heat strain, such as the Physiological Strain Index (53), use core temperature and heart rate maxima and minima to assess the risk of HRI. Farm work is typically perceived as being strenuous. The study results indicate that with modern management practices, most farm laborers do not work at extreme activity rates for hours on end, although some tasks still require intense work rates, e.g., harvesting stone and orchard fruits with ladders (54). However, many tasks are far less taxing, e.g., sorting and packing, which often occurs on the back of a harvester in the field.

Limitations of the study

Lack of acclimatization is an important_risk factor for HRI (55). Acclimatization was not part of this study due to difficulties in organization and logistics, and extreme uncertainty as to when heat waves would occur. Farm laborers often work in close proximity to each other, whether weeding / hoeing, on a tractor-pulled packing-deck (melons), sorting (tomatoes or peppers as they are being harvested), etc. Interference is likely between heart rate monitors of proximal workers. When workers were closer than 1 meter from each other, interference of heart rate recordings occurred with high peaks and deep troughs. Up to 10% of the traces had sufficient interference as to be unusable. In those cases, the accelerometer was essential to estimate work intensity. With these limitations, the simultaneous use of heart rate and accelerometry monitoring provided quality information. The heat pen carried on the external clothing of workers recorded cases of apparent extreme personal environmental heat exposures. Direct sunlight, evaporation of sweat and convection / conduction of body heat are likely to affect the readings of the personal heat pens and overestimate the measurement of environmental heat. Future work will involve comparing the WBGT data that were collected daily from the weather station situated in the same field with the personal and weather station measures (56).

Measurement of Hydration Status

Assessing hydration is complicated because the body consists of not one, but many interconnected fluid containing compartments, each with differing rates of water transfer (57). Many physiological assessments of hydration, e.g., isotope dilution, are not practical in field studies. The consensus suggests that at least two different measures of hydration should be used, the simplest of which are body weight change, plasma osmolality and urine specific gravity or osmolality (25). Because of the difficulties in collecting urine in a field study, body weight change and plasma osmolality were measured here. Morning osmolality is likely to be a good estimate of hydration status as most workers reported not eating or drinking much before coming to work. In an equilibrated state, blood osmolality reflects the concentration of body fluids. The normal range of hydration as measured by osmolality for healthy populations is recognized as being between 275 and 295 mOsm (27, 58), with higher values indicating a greater degree of dehydration (30). However, body weight change provides an accurate index of hydration change when measurements are made more frequently than once a day (25). Based on osmolality, a small percentage of the participants, less than 2%, were classified as dehydrated at the start of the day, and this percentage rose to 6% by the end of the shift. In contrast, based on body weight, 69 participants (11.8%) lost more than 1.5% of their body weight and would be classified as dehydrated. While the two measures of dehydration differed, osmolality and body weight are considered more reliable than estimations made by participants of the volume of liquids they drank (59).

CONCLUSION

A demographically representative sample of California's Latino farm worker population was accessed from a wide range of farm and farm labor operations. Despite work place restrictions and challenging work conditions, physiological monitoring of a wide variety of tasks performed in the summer heat in California's Central and Imperial Valleys was successfully achieved. With some limitations, sufficient data were obtained to allow estimation of worker energy expenditure, work rate intensity, core body temperature, heat and humidity exposure and hydration status.

Workers in many other occupations, e.g., mining, firefighting, and military, have had extensive monitoring and assessment of the physiological risks of HRI. As these are in regulated 'industries' with stable, permanent work forces, prevention of HRI is more easily managed. Farm work, conducted overwhelmingly by immigrant labor, is less regulated, and location, conditions, type of work and day length often vary enormously. Recent technological advances now facilitate the assessment of normal physiological responses to farm work in various degrees of heat index, with the possibility of determining what is safe or dangerous. The techniques described in this paper allow this assessment to begin. The methods used will need refining, but with expected changes in climate, assessing safe levels of exposure to heat and appropriate measures to lower the risk of HRI are urgently needed.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Clinical Significance

Rigorous studies of Heat Related Illness (HRI) are difficult to conduct among farmworkers due to the varieties of fieldwork performed by immigrant laborers. Previous studies used questionnaires to assess HRI risk. Physiologic measurements and methods described in this paper allow objective estimation of HRI risk in farmworkers.

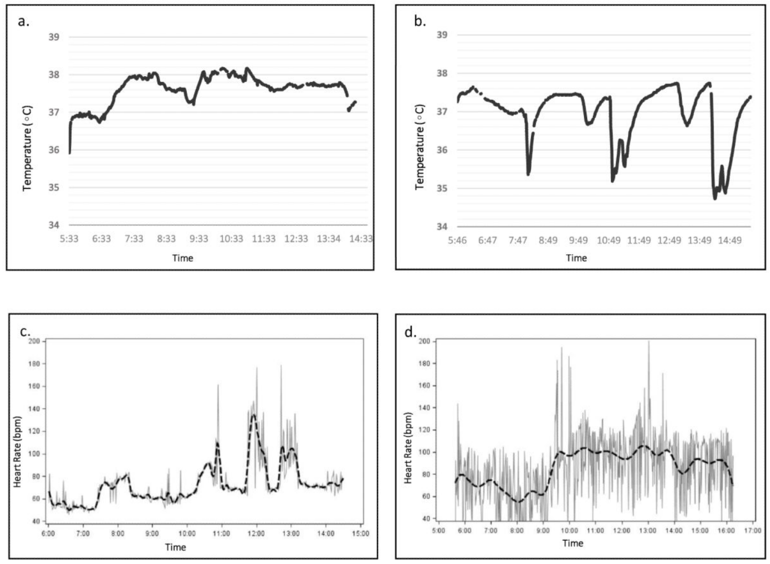

FIGURE 1. Examples of Core Temperature and Heart Rate in Individual Workers

Legend for Figure 1:

1a: Core Temperature recording

1b: Core Temperature recording with drinking dips and recoveries

1c: Heart Rate recording with smoothed spline (dashed)

1d: Heart Rate recording with interference – attenuated smoothing spline (dashed)

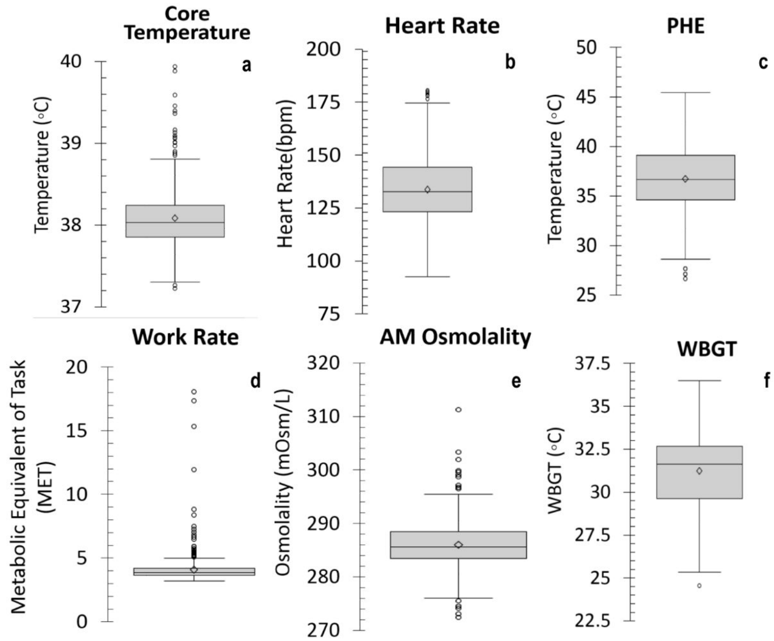

FIGURE 2. Maximal Value or AM Distributions of Physiological Measurements

Legend for Figure 2:

All distributions are for the maximum of a 3-minute moving average except Osmolality which was the morning assessment.

† Personal Heat Exposure measured by a ‘heat pen’

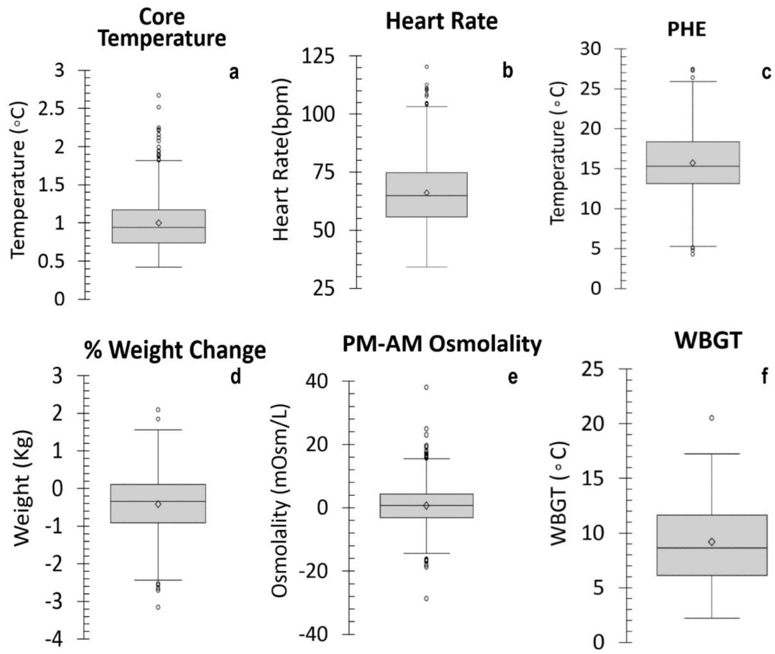

FIGURE 3. Range (Max-Min) of Physiological Measurements

Legend for Figure 3:

All distributions are the maximum - minimum of a 3-minute moving average except the weight change ((post-preshift)/preshift)x 100% and osmolality which was the afternoon - morning assessment.

† Personal Heat Exposure measured by a ‘heat pen’

Table 1

Comparison of the Demographics of CHIPS 2014-5 and NAWS 2013-4

CHARACTERISTIC *	CHIPS n = 587 Mean (SE) Range or *n* (%)	NAWS n = 553 Mean (SE) Range or *n* (%)	*Adjusted p-Value [95% Cl] Difference*
Total	587 (100)	553 (100)	0.99
Females	198 (33.7)	128 (33.8)	[25.2 to 42.6%]
Age (Years)	38.7 (0.61) 18 – 82	39.7 (1.15) 18 - 74	0.45 [−3.7 to 1.7]
Country Born	N = 587	N = 551	
USA	48 (8.2)	44 (9.0)	
Mexico	519 (88.4)	503 (89.8)	0.56
Central America	20 (3.4)	4 (1.2)	
Ethnicity	N = 585	N = 553	
Latino	581 (99.3)	535 (96.0)	**0.009** †
Non-Latino	4 (0.7)	18 (4.0)	
Language Spoken	N = 587	N = 553	
English	25 (4.3)	36 (7.2)	0.42
Spanish	533 (90.8)	492 (90.2)	
Other / Indigenous	29 (4.9)	25 (2.6)	
Years in USA if Immigrated	15.5 (0.61) 0 – 54	19.3 (1.02) 0 - 54	**0.006**† [−6.3 to −1.3]
Years in Agricultural Work	14.3 (0.81) 0 – 56	16.2 (1.30) 0 - 54	0.23 [−5.1 to 1.3]
Hired by	N = 568	N = 553	
Farmer	269 (47.4)	419 (65.6)	
Contractor	299 (52.6)	134 (34.4)	0.23
Paid by	N = 587	N = 552	
Any Type of Piece	127 (21.6)	93 (21.8)	0.99
Hourly / Salary	460 (78.4)	459 (78.2)	
Family Income / Year	N = 564	N= 506	
$ 0 - 5,000	52 (9.2)	6 (1.5)	
5,0001 - 10,000	75 (13.3)	12 (3.2)	
10,001 - 20,000	154 (27.3)	99 (20.8)	
20,001 - 30,000	149 (26.4)	179 (35.5)	
30,001 - 40,000	96 (17.0)	122 (23.4)	**0.0009**†
> **40,000**	38 (6.7)	88 (15.6)	
Education **	N = 314	N = 553	
None	16 (5.1)	21 (2.1)	
Grades: 1-6	152 (48.4)	282 (47.7)	0.39

CHARACTERISTIC *	CHIPS n = 587 Mean (SE) Range or *n* (%)	NAWS n = 553 Mean (SE) Range or *n* (%)	*Adjusted p-Value [95% Cl] Difference*
7-11	81 (25.8)	144 (27.9)	
HS Graduate or More	65 (20.7)	106 (22.3)	

[*] The means and frequencies are unadjusted, the percentages and differences are adjusted.

[**] Only 314 CHIPS respondents were able to state the grade level completed, the remainder estimated the general school level and could not be included in this table.

[†] $p < 0.01$

Table 2

Yields from Field Study Components (N=588)

Date Type	*n* (% of Original 588) Collected		*n* (% of Original 588) Used for Modeling
Core Temperature	579 (98.6)		464 (80.1)
Heart Rate	583 (99.3)		488 (84.3)
Heat Pen	556 (94.7)		550 (93.7)
Accelerometer	574 (97.8)		574 (97.8)
	Pre-shift	**Post-shift**	**Across-shift**
Serum Osmolality	563 (95.91)	581 (98.9)	549 (94.9)
Weight	588	588	588 (100)
Questionnaire*	588	587	587 (99.8)

*One participant who spoke an indigenous language had sufficient Spanish to complete the pre-shift but not the post-shift questionnaire.