



## RESEARCH ARTICLE

# Impacts of weather, work rate, hydration, and clothing in heat-related illness in California farmworkers

Alondra J. Vega-Arroyo PhD<sup>1</sup> | Diane C. Mitchell PhD<sup>2</sup> | Javier R. Castro BS<sup>2</sup> | Tracey L. Armitage MS<sup>1</sup> | Daniel J. Tancredi PhD<sup>3</sup> | Deborah H. Bennett PhD<sup>1</sup> | Marc B. Schenker MD<sup>1</sup>

<sup>1</sup>Department of Public Health Sciences, School of Medicine, University of California, Davis, California

<sup>2</sup>Center for Health and the Environment, University of California, Davis, California

<sup>3</sup>Department of Pediatrics and Center for Healthcare Policy and Research, University of California, Davis Medical School, Sacramento, California

**Correspondence**

Marc B. Schenker, MD Center for Health and the Environment, University of California Davis, 1250 Old Davis Road, Davis, CA 95616. Email: mbschenker@ucdavis.edu

**Funding information**

CDC-NIOSH, Grant/Award Numbers: R01OH010243, U54OH007550

**Abstract**

**Background:** The primary aim of this study was to investigate the effects of work rate, hydration status, and clothing on core body temperature (CBT) on California farmworkers.

**Methods:** Two hundred and eighty-seven farmworkers were recruited in Summer 2015, with 259 participants having sufficient data for analysis. We collected CBT, ambient temperature, work rate, body weight loss, and clothing worn by each participant throughout the work day and demographic data from a questionnaire.

**Results:** Multiple regression with CBT as the outcome was used to determine the adjusted associations between CBT, environmental heat load, and worker characteristics. The multivariate regression model showed statistically significant associations of CBT with work rate ( $\beta = .006$ , 95% CI [0.004, 0.009]) and wet-bulb globe temperature ( $\beta = .03$ , 95% CI [0.017, 0.05]).

**Conclusion:** Results suggest that among our population workload is the primary modifiable risk factor for heat-related illness. As expected, the ambient temperature was also associated with higher risk.

**KEYWORDS**

agricultural workers, core body temperature (CBT), farmworkers, heat-related illness, heat stress, HRI

## 1 | INTRODUCTION

The state of California produces a third of the country's vegetables as well as two-thirds of its fruits and nuts.<sup>1</sup> Most of these commodities are grown and cultivated during the summer months, where temperatures can rise above 32°C and agricultural workers sometimes conduct arduous work for up to 12 hours a day under direct sunlight. It is these working conditions that put farmworkers at risk for heat-related illnesses (HRI) such as heat rashes, heat cramps, heat exhaustion, and heat stroke.

An increased risk in HRI occurs when an individual's thermoregulatory mechanism fails to maintain homeostasis. The human core body temperature (CBT) is regulated within a narrow band between 36-38°C.<sup>2</sup> An individual's response to elevated CBT varies. Generally, when an individual's CBT reaches 38°C mild symptoms of heat-related illness begin to manifest, such as elevated heart rate, respiratory rate, profuse sweating, headaches, and weakness, when not supported by proper hydration and cool resting places.<sup>3-5</sup> The CBT is a subclinical symptom that is usually assessed when a person is experiencing heat stress or at risk for HRI.<sup>6</sup> Body temperature is affected by humidity, radiant, and convective heat, and external heat load from the environment, as well as heat generated by a person's

Institution at which the work was performed: University of California, Davis.

metabolic work. When challenged, humans use sweating as a mechanism to cool their CBT when it rises above normal.<sup>7</sup> CBT may not be maintained in a hypohydrated state due to a reduced capacity to sweat, which can increase CBT.<sup>8</sup> The pay and work systems encourage workers to ignore symptoms of HRI or any illness that may increase the risk of HRI as workers will not “self-regulate” to slow down or take a water/rest break.

Employers in California are required to provide water and encourage their workers to drink a cup (8 oz) water every 15 minutes to stay hydrated on hot days.<sup>9</sup> Previous quantitative research in the city of Mendota, which is in the Central Valley of California, found that farm workers ( $n = 474$ ) were not drinking enough water to stay hydrated throughout the day.<sup>10</sup> Another study conducted in Central America among 106 sugarcane harvesters indicated 30% of the participants experienced dehydration symptoms (dry mouth and dysuria) at least once a week.<sup>11</sup> Similarly, 96 crop workers who have experienced HRI in Washington reported drinking less often than once every 30 minutes.<sup>12</sup> Lastly, a study of 100 Oregon farmworkers found that 30% of the participants did not drink water at least once per hour during their shift.<sup>13</sup>

The California Occupational Safety Health Administration (Cal-OSHA) has regulations and recommendations to help prevent heat illness in agricultural workers. It requires facilities to provide water, shade, emergency response procedures, and HRI preventive training as part of their Heat Illness Prevention plan (Cal-OASHA-reg 2015). The conditions contributing to HRI have been studied in the military and among athletes<sup>14</sup> who undergo periods of extreme exertion. Findings based on bursts of exertion in military studies are the basis for field work regulations by the Cal-OSHA<sup>9,15</sup> because heat illness has not been researched widely among agricultural workers. Military training conditions are tightly controlled unlike agricultural field work and findings from such studies may not apply to civilian workers.<sup>16</sup> Unlike private sector agricultural workers military training activities include mandatory rest periods and water breaks on a prescribed schedule. Agricultural workers can only be cautioned to rest and drink, and they frequently ignore suggestions to maintain their earnings.<sup>17</sup>

In addition, the work/rest periods provided by Cal-OSHA, based on military guidelines, require knowing the work rate (Watts) and wet-bulb globe temperature, which are not readily available in the agricultural fields.<sup>18</sup> To our knowledge, OSHA has not calculated the work rate for each task performed in the field, which makes it hard for farmers to follow the work/rest suggested schedule.<sup>19</sup>

Understanding all the factors contributing to HRI: the environmental conditions, an individual's state of acclimation, workload, clothing, and hydration level in outdoor occupational workers is essential, especially since it is likely that global climate change will increase the environmental heat load above current levels.<sup>20</sup> The Inter-Governmental Panel on Climate Change (IPCC) estimated that mean global temperature will increase 1.8°C–4.08°C by 2100<sup>21</sup> affecting workers' health.<sup>22</sup> Cubasch et al<sup>23</sup> predict that heat waves will become more frequent, more intense and longer-lasting due to a warmer climate with increased mean temperature. The potential

magnitude of HRI is a serious concern and needs to be investigated further since there are over a half a million farmworkers in California<sup>1</sup> and over 2.5 billion farmworkers in the world.<sup>24</sup>

We hypothesize that in addition to the environmental temperature, modifiable factors as work rate, clothing and hydration will be associated with the risk of HRI as defined by an increase in CBT. We investigated the adjusted associations of environmental conditions, workload, clothing, and hydration with CBT of California farmworkers as part of the California heat illness prevention study.

## 2 | METHODS

### 2.1 | Participants

We enrolled 287 farm workers in the summer months (June–September) of 2015 from a convenience sample of 14 farms from California's Central and Imperial Valleys. Permission from the farm owner was obtained to recruit workers into the study a day before data collection. Field staff explained the purpose of the study and the requirements in Spanish to all workers. Interested workers signed a consent form. The inclusion and exclusion criteria are described in Mitchell et al<sup>25</sup> Briefly, a male or female farmworker where included in the study if they carried out normal field tasks, worked outside in the fields for a full shift, and if they had a normal body temperature at the start of the shift (measured by a tympanic ear thermometer).<sup>26</sup> Subjects were excluded if they were under the age of 18, worked less than a full shift, were unable to understand and answer questions in Spanish or English, were unable to swallow large pills, had an implanted electro-medical device such, or if their preshift temperature was 37.5°C or higher.<sup>25</sup> Subjects who participated a single day in the study were given a gift card for their time and effort.

Demographic and individual risk variables possibly associated with an increase in CBT throughout the day were selected a priori based on a review of the literature<sup>10,12,17,26</sup> and feasibility of collecting data in the field. Demographic variables included sex (male vs female) and age (continuous). Occupational variables collected were years in agricultural work (continuous), who the worker was hired and supervised by (farmer, contractor, other), how the worker was paid (by the hourly, piece, combination of hour and piece rate or salary), and how often the worker was paid (weekly, fortnightly, other). Questionnaires were interviewer administered in Spanish or English, depending on participant preference to ensure literacy level did not bias data collection.

All study procedures were approved by the University of California, Davis Institutional Review Board.

### 2.2 | Core body temperature

Participants swallowed a CorTemp<sup>TM</sup> HT15002, ingestible wireless temperature transmitter probe with water before they started their work shift (CoreTemp HTI technologies, St. Palmetto, Florida). The probe (heat pill) transmitted core temperature measurements at 1-minute intervals into a recorder device, which they wore on their

belts. The heat pill was precalibrated on a water bath to ensure that heat pills stabilized at the designated temperature. There was a systematic bias reported in the water bath when pills were precalibrated, a reading higher by 0.07°C to 0.15°C, which was considered acceptable by Hunt and Stewart.<sup>27</sup> Because the heat pill moves through the intestines, which are at variable distances from the stomach, a cold drink will on occasion cause the temperature sensed to plummet below physiological temperatures. This effect has been widely noted.<sup>28,29</sup> We removed physiologically implausible points before analysis of the CBT.

For analysis, we created a 3-minute moving average for each individual's CBT beginning 3 hours after the start of each participant's shift to allow the heat pill to exit the stomach. The outcome measure was the maximum of the 3-minute temperature moving average. Our goal was to classify participants who were at risk for HRI. The National Institute for Occupational Safety and Health classifies an employee as having excessive heat strain if they have a CBT greater than 38.5°C.<sup>5</sup> This threshold value is also in accordance with the American Conference of Governmental Industrial Hygienists<sup>4</sup> heat stress guidelines for acclimatized individuals (2014). Since we do not have the acclimatization margin for the participants in this study and are also trying to assess the risk of HRI (before symptoms are apparent), we used slightly lower criteria to be able to capture all workers who are at risk of HRI. Even though workers tend to work even if their CBT is greater than 38.5°C, their risk for HRI increases. Thus, we used a CBT measurement of 38°C as a marker for an individual being at increased risk for HRI (or having an elevated CBT).

### 2.3 | Work rate

An Actical accelerometer (Actical™ Philips Respironics, Murrysville PA) was worn by participants to assess individual daily activity level. Accelerometry quantifies the amount of time spent in physical activity as well as intensity.<sup>30</sup> The accelerometer was secured on the participant's belt using a zip tie at the upper part of the hip (the iliac crest). The worker wore it for the entire work shift and it collected the total physical activity counts per minute (cpm).

For analysis, we used the mean physical activity count over the two hours prior to a participant's maximum CBT.

### 2.4 | Hydration status

Individuals were weighed using a medical scale, Seca™ Model 874 scale (Seca GMBH & CO. Hamburg, Germany), before and after their shift. Participants were weighed in a base layer of clothing, removing all excess layers, equipment, and shoes. Typically, a base layer consisted of undergarments, such as underwear (brassiere for women), pants, T-shirt, and socks. If a participant was wearing multiple shirts, they were asked to remove all except the first layer. Field staff ensured that participants were weighed with the same clothes in the morning and in the afternoon. We did not account for base clothing change in weight throughout the work shift (i.e. got

heavier due to sweat). Employees who have a weight loss of more than 1.5% body weight over a work shift have been shown to be at increased HRI risk (ACGIH 2008).<sup>31</sup> Participants were considered hypohydrated if they lost more than 1.5% body weight over the work shift and euhydrated otherwise (ACGIH 2014).<sup>32-34</sup>

### 2.5 | Clothing

A clothing inventory was administered by staff, which recorded all articles of clothing that a participant was wearing. Categories included: headgear (hat, wide-brimmed hat, beanie), shirts (sleeve length, color, and material), and pants (length, color, and material). Staff assumed that participants were wearing underwear and for female participants a brassiere. Two heat gain insulation values were calculated: an ensemble insulation value and a headgear heat gain insulation value. Heat gain insulation values were retrieved from a thermal manikin and a thermal manikin head in the Reischl Laboratory at Boise State University. Two different heat gain insulation values were used because the thermal manikin head and the thermal manikin body operated at slightly different temperatures, which makes them incomparable.

### 2.6 | Weather

Two instruments were used to collect weather information in the field. The QUESTemp 36 thermal environment monitor (Quest Technologies, Inc., Oconomowoc, WI) was placed in the field adjacent to the working participants. It stands one meter tall and collects dry bulb temperature, humidity, wet-bulb globe temperature (WBGT; outside and inside), and globe temperature. Data were collected across the work shift. When data were not available from the QUEST, we used a HOBO U30 weather station on a 3-meter tripod (Onset Computer Corp Bourne, MA), that is, the monitor was three meters above the ground. Data were collected over the same time period (shift start to finish) as for the QUEST. All field staff were trained on collecting data, as well as supervised regularly to ensure protocols, were being followed for all field tasks.

In this study, we used two different indices to measure temperature, WBGT, and the heat index. We calculated the average temperature for the 2 hours before the time a participant reached his/her maximum CBT. Since the HOBO did not provide the WBGT directly, we used the formula in Lemke et al<sup>35</sup> to calculate workplace WBGT. Neither instrument provided the heat index; therefore, it was calculated using the formula in Rothfus<sup>36</sup> which combine the effects of temperature and humidity.

### 2.7 | Statistical analysis

To be part of this analysis a participant needed to have complete: CBT, weather conditions for the day, work rate, demographic information, and clothing insulation data. Mitchell et al<sup>25</sup> describes how data was cleaned and assessed for sufficiency. The final sample yielded 259 participants with sufficient data for analysis. Summary

statistics were calculated for the CBT and potential risk factors as well as demographic variables. Data were categorized, and unadjusted associations between CBT and risk factors were tested for statistical significance using Student's *t* test for continuous variables and chi-square tests for categorical variables. To perform the chi-square tests, CBT was dichotomized: normal, indicating a maximum CBT less than 38°C; elevated, indicating a maximum CBT greater than or equal to 38°C. A participant's mean work rate and mean ambient temperature were calculated two hours prior to reaching the maximum CBT so that we could have a temporal coherent time-period for all participants. If there was a  $P \leq 0.1$  in the univariate associations between potential risk factors, demographic variables, and CBT, then variables were tested in a multivariate regression model. The final multivariate regression model included variables that had a statistical significance of  $P \leq 0.05$  or if previous literature had shown an association with heat-related illness.<sup>10,12,17,22,26</sup> All analyses were conducted using SAS 9.4 (SAS Institute, Inc., Cary, NC).

### 3 | RESULTS

#### 3.1 | Population characteristics

Most participants were male (64.9%), from Mexico (84.8%), and self-identified as Latino (96.9%) (Table 1). Overall this sample had on average a 7<sup>th</sup>-grade education, spoke Spanish at home (90.0%), and in general, the farmworker families earned very modest incomes; about 30% had a family income under \$20,000 per year. We compared demographic factors of the forty-five percent of workers who had a CBT greater than 38°C with those who maintained homeostasis. The only significant difference was that workers with normal CBT had a higher income compared with those with elevated CBT. Workers had been in field work for an average of 13.4 years (standard deviation [SD] 10.7 years; Table 2). Fifty-two percent of the workers were hired by a contractor, and most were paid hourly (79.9%). None of these work attributes were significantly associated with elevated CBT.

#### 3.2 | Primary Variables

Forty-five percent of workers had a CBT greater than or equal 38°C, compared to fifty-five percent of workers who had a CBT less than 38°C (Table 3). Approximately 15% of the workers were classified as hypohydrated using the 1.5% body fat loss cut-off as a measure of dehydration. The mean WBGT experienced during data collection was 25.3°C (SD 3.8) compared to the heat index calculated was 29.2°C (SD 4.0). Daily activity cpm were used to assess work rate and the total cpm for workers was 360.9 (SD 243.7). Clothing ensemble insulation heat gain averaged 79.1 (SD 13.7) watts and heat gear insulation heat gain averaged 12.6 (SD 8.3) watts.

#### 3.3 | Physiologic variables

In this sample, workers who had an elevated maximal CBT were more likely to lose more than 1.5% body mass than those with normal CBT

(Table 3; 58.8% vs 41.2%,  $P = 0.03$ ). The mean heat index temperature experienced in the two hours prior to reaching their maximum temperature was on average 29°C (SD 4.0°C) for the participants. The WBGT, which was calculated for the exact time window as the heat index, was approximately 4°C less than the heat index (mean 25.6, SD 3.8). Participants whose physical activity was higher (414.8 cpm [SD 251.6] vs 315.7 [SD 228.4],  $P = 0.001$ ) during the two hours prior to reaching their maximum CBT, experienced an elevated CBT  $\geq 38.5^\circ\text{C}$ .

### 3.4 | Multivariable models

A final multivariable linear regression model included sex, age, hydration status, activity counts, clothing insulation, headgear insulation, and mean WBGT in relation to maximum CBT (Table 4). Women were marginally more likely to have a higher CBT ( $P = 0.08$ ), as were younger workers, but the association with age was not statistically significant. A mean work rate increase of 1000 cpm was associated with an increase of CBT of 0.6°C (95% CI, 0.4-0.9), while all other predictors remain constant. Hypohydrated compared with euhydrated participants, with the same values on the other predictors, had an increase in maximum CBT of 0.08°C (95% CI, -0.05-0.21). Likewise, keeping all predictor variables the same and increasing the mean WBGT by ten degrees Celsius, resulted in a mean increase in maximum CBT of 0.3°C (95% CI, 0.05-0.3). The mean heat index was also significantly associated with CBT when substituted for WBGT in the multivariable model (parameter estimate 0.2,  $P = 0.006$ ; model not shown). The standardized estimates, also presented, are defined as the estimates that result when all variables are standardized to a mean of 0 and a variance of 1. Numerically, a participant's work rate had the highest standardized value (0.33), meaning that it had the largest effect in the model. Clothing insulation and head gear insulation did not appear to be a significant factor in the model.

## 4 | DISCUSSION

The primary findings of this analysis are the independent associations between an increase in maximum CBT and both the mean work intensity and temperature indices, WBGT, and heat index, in the preceding 2 hours. No other traditional risk factors, for example, age, sex, or modifiable factors, such as clothing and headgear heat gain insulation, were associated with an observed increase in maximum CBT. In this study, men and women differed significantly in both the top and bottom layers of clothing worn. Women wore tight layers of clothing compared with the men working in the fields. Women wore more likely to wear sweatshirts and cotton pants (data not shown; Vega-Arroyo et al, in process).<sup>37</sup> Previous studies have shown that a strong correlation exists between clothing insulation and sex.<sup>13,26</sup>

The mean WBGT and mean heat index were highly correlated ( $r = 0.87$ ). When comparing the WBGT with the heat index, Bernard et al<sup>38</sup> found that the heat index underestimates the WBGT at high relative humidity. In California, summers are known to have

**TABLE 1** CHIPS participant demographics (n = 259)

Characteristic	Total n = 259 (100%) n (column %)	Core body temperature <38°C n = 141 (54.4%) n (row %)	Core body temperature ≥38°C n = 118 (45.6%) n (row %)	P value <sup>a</sup>
Sex				
Male	168 (64.9)	93 (55.4)	75 (44.6)	.69
Female	91 (35.1)	48 (52.7)	43 (47.3)	
Country born				
USA	26 (10.0)	16 (61.5)	10 (38.5)	.71
Mexico	217 (84.8)	117 (53.9)	100 (46.1)	
Central America	16 (6.2)	8 (50.0)	8 (50.0)	
Ethnicity				
Latino	250 (96.9)	135 (54.0)	115 (46.0)	.63
Non-Latino	8 (3.1)	5 (62.5)	3 (37.5)	
Language spoken at home				
English	11 (4.3)	9 (81.8)	2 (18.2)	.10
Spanish	233 (90.0)	126 (54.1)	107 (45.9)	
Indigenous/other	15 (5.7)	6 (40.0)	9 (60.0)	
Family income/year				
\$0-5,000	14 (5.5)	8 (57.1)	6 (42.9)	.04 <sup>c</sup>
5,001-10,000	34 (13.4)	22 (64.7)	12 (35.3)	
10,001-20,000	72 (28.5)	35 (48.6)	37 (51.4)	
20,001-30,000	65 (25.7)	26 (40.0)	39 (60.0)	
30,001-40,000	49 (19.4)	33 (67.4)	16 (32.6)	
>40,000	19 (7.5)	12 (63.2)	7 (36.8)	
	<b>Mean (standard deviation)</b>	<b>Mean (standard deviation)</b>	<b>Mean (standard deviation)</b>	
Age, y	38.4 (11.7)	39.6 (12.1)	36.9 (11.2)	.06
Years in school <sup>d</sup>	7.48 (3.7)	7.39 (3.8)	7.6 (3.6)	.74

Abbreviation: CHIPS, California heat illness prevention study.

<sup>a</sup>P values for categorical variables were calculated using a chi-square test.

<sup>b</sup>P values for continuous variable were calculated using a Student's *t* test.

<sup>c</sup>P value is significant at a <0.05 level using the chi-square test.

<sup>d</sup>This result is based on n = 151.

relatively low humidity<sup>39,40</sup>, suggesting that the heat index and WBGT are comparable without temperature or humidity biases.

There is no report to our knowledge that has studied the modifiable work rate of agricultural workers and its association with CBT. Workers who work more intensely over their shift were more likely to have a CBT ≥ 38°C compared with those workers who had a CBT < 38°C. Since we did not note how many or when breaks were taken, we do not know what caused the increase in work rate aside from the actual work.

The thermoregulatory system begins trying to cool the human body when metabolic output increases.<sup>7</sup> Past studies of military subjects have observed the effects of exertional workload and its effects on HRI. The U.S. Army came up with a work/rest and water consumption chart for an average-size acclimated individual wearing specific military garments.<sup>41</sup> They found this chart helped decrease the incidence of heat-related illness during training. Creating a similar chart for agricultural workers based on crop task and using data from studies like this one, which looks specifically at farm work, would be a tool to help prevent heat-related illness.

The biggest challenge to reduce HRI risk among farmworkers is to maintain income for farmworkers who reduce their productivity due to environmental conditions. This is particularly true when the majority of workers are paid by piece rate and thus would decrease

their income by reducing their work productivity. Statewide regulations that include mandatory work reduction would at least level the playing field for all agricultural workers in the state. Other solutions should also be tried, including scheduling work at cooler hours of the day, introducing more effective and acceptable hydration systems, and implementing mandatory hydration regimens.

All of our study farms provided water at close distance to their workers, but, even so, we found that 15% of workers in our sample were hypohydrated (≥1.5% body weight loss) by the end of the workday (Table 3). The body's thermoregulatory system uses sweat as the primary mechanism to either cool or maintain the CBT within a normal range.<sup>42</sup> When that system is perturbed due to excess heat gain from physical labor and clothing, then the fluid consumption must be adjusted for the increase in sweat evaporation. If an individual is not drinking enough water throughout the day and/or starting the day hypohydrated, then their risk for elevated CBT is increased.<sup>43</sup>

#### 4.1 | Limitations

First, we used a convenience sample, which can limit the generalizability of the results. Demographically the population was representative,<sup>25</sup> and there is no reason to believe that participation in the study once we were at the farm was driven by factors related to an increase in CBT.

**TABLE 2** CHIPS participants' work attributes, such as pay, pay rate, and employment (n = 259)

Attribute	Total n = 259 (100%) n (column %)	Core body temperature <38°C n = 141 (54.4%) n (row %)	Core body temperature ≥ 38°C n = 118 (45.6%) n (row %)	P value <sup>a</sup>
Who are you hired by?				
Farmer	110 (43.0)	57 (51.8)	53 (48.2)	.81 <sup>c</sup>
Contractor	135 (52.7)	72 (53.3)	63 (46.7)	
Other	11 (4.3)	10 (90.9)	1 (9.1)	
How are you paid?				
By hour	207 (79.9)	116 (56.0)	91 (44.0)	.18 <sup>d</sup>
Salary	8 (3.1)	5 (62.5)	3 (37.5)	
Piece rate (individual or crew)	30 (11.3)	14 (46.7)	16 (53.3)	
Combination of hour and piece rate	14 (5.4)	6 (42.9)	8 (57.1)	
How often are you paid?				
Weekly	187 (72.2)	99 (52.9)	88 (47.1)	.74
Fortnightly	53 (20.5)	31 (58.5)	22 (41.5)	
Other	19 (7.3)	11 (57.9)	8 (42.1)	
	Mean (standard deviation)	Mean (standard deviation)	Mean (standard deviation)	P value <sup>b</sup>
Years in agricultural work	14.4 (11.7)	15.3 (12.4)	13.4 (10.7)	.18

Abbreviation: CHIPS, California heat illness prevention study.

<sup>a</sup>P values for categorical variables were calculated using a Chi-square test.

<sup>b</sup>P values for continuous variable were calculated using a Student's *t* test.

<sup>c</sup>P value is for chi-square statistic between farmer and contractor. P value for all three categories is 0.04.

<sup>d</sup>P value is for chi-square statistic for non-incentivized work (by hour and salary) vs. incentivized work (piece rate and combination of hour and piece rate). P value for all four categories is 0.59.

Second, we only followed participants for a day. If we could follow participants through multiple days or a season, a more complete picture of the worker characteristics, work rate, hydration behaviors, and environmental conditions would assist model building. However, such a study would be costly, and unlikely to be tolerated by the employer or their employees, whose cooperation we relied upon. We were unable to quantify the actual amount of beverage drunk objectively, the real-time

hydration status, the actual temperature, and humidity experienced by an individual, or some of the conditions that may predispose a worker to heat illness. Third, one of the major contributors of HRI found by previous research is the lack of acclimatization,<sup>44-46</sup> a factor that we did not include in our study because over 90% of our sample was acclimatized. Fourth, we were unable to assess whether based clothing changed in weight (i.e., got heavier due to sweat) since we did not have

**TABLE 3** CHIPS participants primary variables to assess increased core body temperature (n = 259)

Variable	Total n = 259 (100%) n (column %)	Core body temperature <38°C n = 141 (54.4%) n (row %)	Core body temperature ≥ 38°C n = 118 (45.6%) n (row %)	P value <sup>a</sup>
Hydration defined by weight loss				
<1.5% body weight loss	222 (85.7)	124 (55.9)	98 (44.1)	.26
≥1.5% body weight loss	37 (14.3)	17 (46.0)	20 (54.0)	
	Mean (standard deviation)	Mean (standard deviation)	Mean (standard deviation)	P value <sup>b</sup>
WBGT (°C)	25.6 (3.8)	24.9 (3.8)	26.5 (3.7)	.0006 <sup>c</sup>
Heat index (°C)	29.2 (4.0)	28.4 (3.7)	30.1 (4.2)	.0007 <sup>c</sup>
Daily activity counts per minute	360.9 (243.7)	315.7 (228.4)	414.8 (251.6)	.001 <sup>c</sup>
Clothing ensemble insulation heat gain (Watts)	79.1 (13.7)	79.3 (13.1)	78.9 (14.5)	.85
Head gear insulation heat gain (Watts)	12.6 (8.3)	12.3 (8.2)	13.0 (8.4)	.50

Abbreviations: CHIPS, California heat illness prevention study; WBGT, wet-bulb globe temperature.

<sup>a</sup>P values for categorical variables were calculated using a chi-square test.

<sup>b</sup>P values for continuous variable were calculated using a Student's *t* test.

<sup>c</sup>P value is significant at  $\alpha < 0.05$  level.

**TABLE 4** Regression coefficients for multiple linear regression of core body temperature associated with hydration status, wet-bulb globe temperature (WBGT), activity level, and clothing insulation heat gain on core body temperature

	Parameter estimate	95% confidence interval	Standardized estimate <sup>a</sup>	95% confidence interval	P value
Female	0.11	(-0.01, 0.25)	0.12	(-0.01, 0.2)	.08
Age, y	-0.0007	(-0.005, 0.004)	-0.018	(-0.14, 0.1)	.75
Hydration (% weight loss)	0.08	(-0.05, 0.21)	0.07	(-0.04, 0.2)	.22
WBGT, °C	0.03	(0.017, 0.05)	0.25	(0.13, 0.37)	<.0001 <sup>b</sup>
Activity level (per 1000 cpm)	0.6	(0.4, 0.9)	0.33	(0.21, 0.45)	<.0001 <sup>b</sup>
Clothing ensemble insulation heat gain (Watts)	-0.00002	(-0.004, 0.004)	-0.0005	(-0.12, 0.12)	.99
Head gear insulation heat gain (Watts)	0.001	(-0.006, 0.008)	0.02	(-0.1, 0.2)	.71

<sup>a</sup>Standardized estimates are defined as the estimates that result when all variables are standardized to a mean of 0 and a variance of 1.

<sup>b</sup>P value is significant at a <0.05 level.

any tools to measure this difference in the field. Even though we are unsure about the level of bias this created, we believe it is less likely to be significant in the drier atmosphere of California compared with more humid states. This could be better assessed in a laboratory setting to produce instruments that will be able to assess sweat and sweat rates for individuals in the outdoor work setting. Also, we did not notate the breaks that were taken by participants and how much they hydrated throughout the day. Without notating the time of breaks, the data can only show us when there was increased activity, but we cannot address why the peak occurred. The peak could have occurred right after a break or from increased work activity. Although we did not note this, the work rate variable relies on when the increased CBT occurred, not when there was a peak in activity. We were unable to gather how much a person drank to stay hydrated since we were not in a laboratory setting where we could measure all fluids. To assess hydration, we used the best proxy variable available for data collection in the field. Finally, having missing data for the Actical, Quest, and HOB0 was a limitation since that decreased our sample size. Although these limitations exist, we believe that the results of this study are valid and can be generalizable to farmworkers who work in similar environmental conditions.

Strengths of the study include using objective physiological measures, including direct CBT measures by an ingestible sensor, physical activity, and hydration assessments and weather station data. Previous studies of the risk factors contributing to HRI in farmworkers have relied on subjective questionnaires to estimate HRI symptoms, work rates, hydration status and sometimes ambient temperatures.<sup>10-12,41</sup> A major strength of the analysis is that we are the first to document a combination of the CBT, work rate, hydration status, clothing insulation factors, and the environmental weather conditions for so many farmworkers across the large variety of California field settings. Previous studies in this field have only been conducted with small sample sizes, whereas we were able to collect data for 259 participants on multiple farms across the broad spectrum of agricultural commodities grown in California.<sup>11-13,26</sup>

## 5 | CONCLUSION

To our knowledge, this is the first paper to look at objectively collected data on ambient temperature, work rate, hydration, and clothing and assess their combined contribution to CBT. Only modifiable work rate and nonmodifiable WBGT were associated with increased CBT. None of the workers on their study day reported HRI symptoms, therefore, it could be interpreted that California regulations, as followed by the study farms, protected the workers. Behavioral research has shown that, even if workers are provided with water and opportunities to rest in the shade, they may not take those opportunities.<sup>17,47,48</sup> Fifteen percent of workers were hypohydrated by our definition and 45% had a body temperature over 38°C (for at least 3 minutes), which suggests workers were at risk for HRI. This analysis suggests the most important action to reduce the risk of HRI in farmworkers on hot California summer days is to find ways to decrease the mean work rate.

## ACKNOWLEDGMENTS

The authors would like to thank all the farmworkers, the farms, and the labor contractors, who gave their time and attention this study. We are extremely grateful for the dedication, skill, and discipline of our field team: Jose Gutierrez, Melissa Franco, J. Carlos Piña, Leslie Olivares, Eduardo Delgadillo Alfaro, Maria Rangel, Johnny Wylie, Lorena Romero Solano, Ana Hernandez Cortez, and Wendy Mazariegos. The study was funded by Grant/Cooperative Agreement Numbers R01OH010243 and U54OH007550 from CDC-NIOSH. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of CDC-NIOSH.

## CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

**DISCLOSURE BY AJIM EDITOR OF RECORD**

None.

**AUTHOR CONTRIBUTIONS**

Vega-Arroyo participated in the conception of the work. She collected the data, analyzed it and interpreted the data for this manuscript. Vega-Arroyo also drafted the work. She is accountable for all aspects of the work and ensuring its accuracy. Mitchell participated in the conception as well as the design of the work. She contributed to the acquisition of the data, analysis of the data as well as interpreting the data. Mitchell also revised the work multiple times for important intellectual content. Castro participated in the acquisition and analysis of the data and contributed in the editing process. Armitage was instrumental in the design of data sets, methods and analysis of the data as well as the editing process. Tancredi contributed to the design, analysis, and interpretation of the work. Bennett participated in the conception and the design of the work, as well as the analysis and the interpretation of the data. She also revised the work multiple times for important intellectual content. Schenker participated in the conception and design of the work. He also revised the work and has final approval of the version published.

**ETHICS APPROVAL AND INFORMED CONSENT**

All study procedures were approved by the University of California, Davis Institutional Review Board.

**DISCLAIMER**

None.

**REFERENCES**

- Martin P, Hooker B, Akhtar M, Stockton M. How many workers are employed in California agriculture? *Calif Agr*. 2017;71(1):30-34. <https://doi.org/10.3733/ca.2016a0011>
- Grubenhoff JA, du Ford K, Roosevelt GE. Heat-related Illness. *Clin Pediatr Emerg Med*. 2007;8:59-64.
- Becker JA, Stewart LK. Heat-related illness. *Am Fam Physician*. 2011;83:1325-1330.
- ACGIH-2011 American Conference of Governmental Industrial Hygienists. Documentation of the threshold limit values and biological exposure indices; p. 2002-2100. Cincinnati, OH: American Conference of Governmental Industrial Hygienists; 2011. 2002-2011.
- Eisenberg J, Methner M. Evaluation of heat stress, heat strain, and rhabdomyolysis in park employees. *Health Hazard Evaluation Program Center for Disease and Prevention*. 2014.
- Bricknell M, et al. Heat illness – a review of military experience (Part 2). *J R Army Med Corps*. 1996;142:34-42.
- Arens E, Zhang H. The skin's role in human thermoregulation and comfort. In: Pan N, Gibson P, eds. *Thermal and moisture transport in fibrous materials*. Cambridge, UK: Woodhead Publishing Ltd; 2006.
- Coris EE, Ramirez AM, Van Durme DJ. Heat illness in athletes. *Sports Med*. 2004;34:9-16. <https://doi.org/10.2165/00007256-200434010-00002>
- Cal-OSHA-reg. Heat illness prevention regulations 2008-2015. 8.C.O.S.a.H. Administration. 3395.
- Stoecklin-Marois M, Hennessy-Burt T, Mitchell D, Schenker M. Heat-related illness knowledge and practices among California hired farm workers in The MICASA Study. *Ind Health*. 2013;51(1): 47-55.
- Crowe J, Nilsson M, Kjellstrom T, Wesseling C. Heat-related symptoms in sugarcane harvesters. *Am J Ind Med*. 2015;58: 541-548.
- Spector JT, Krenz J, Blank KN. Risk factors for heat-related illness in Washington crop workers. *J Agromedicine*. 2015;20:349-359.
- Bethel JW, Harger R. Heat-related illness among Oregon farm-workers. *Int J Environ Res Public Health*. 2014;11:9273-9285.
- OSHSB. Occupational safety and health standards board documents cited to support rulemaking—heat illness. Retrieved September 9, 2016, from [http://www.dir.ca.gov/oshsb/Heat\\_illness\\_prevention.html](http://www.dir.ca.gov/oshsb/Heat_illness_prevention.html)
- Cal-OSHA. Water. Rest. Shade. 2010, from <http://www.99calor.org/campaign/>.
- Cooper SP, Bureau K, Frankowski R, et al. A cohort study of injuries in migrant farm worker families in south Texas. *Ann Epidemiol*. 2006;16:313-320.
- Courville MD, Wadsworth G, Schenker M. We just have to continue Working. *Farmworker self-care and heat-related illness. Journal of Agriculture, Food Systems, and Community Development*. 2016:1-22. Advance online publication. <https://doi.org/10.5304/jafscd.2016.062.014>
- United States Department of Labor. Section III Chapter 4. Retrieved January 28, 2019 from [https://www.osha.gov/dts/osta/otm/otm\\_iii/otm\\_iii\\_4.html#TLV](https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html#TLV).
- Mitchell Diane C, Tracey Javier Castro, Daniel LArmitage, Tancredi J, Bennett Deborah H, Schenker Marc B. Physical activity and common tasks of California farm workers: California Heat Illness Prevention Study (CHIPS). *Journal of Occupational and Environmental Hygiene*. 2018;15(12): 857-869. <https://doi.org/10.1080/15459624.2018.1519319>
- Climate-CHIP. Climate CHIP 2016 [Interactive web site for current and future predictions of climate around the world]. Available at: <http://www.climatechip.org/>. Accessed June 2016.
- IPCC. Fourth assessment report. Geneva, Inter-governmental Panel on Climate Change. Cambridge: Cambridge University Press; 2007. Available from [www.ipcc.ch](http://www.ipcc.ch).
- Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health, and productivity—an increasing challenge for low and middle-income countries during climate change. *Glob Health Action*. 2009;2:2047. (10.3402/gha.v2i0.2047.)
- Cubasch U, et al. In: Houghton JT, ed. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge: Cambridge Univ. Press; 2001:pp. 525-582.
- Food and Agriculture Organization of the United Nations. FAO Statistical Yearbook 2005-2006. <http://www.fao.org/docrep/009/a0490m/a0490m00.htm>.
- Mitchell D, Castro J, Armitage T, et al. Recruitment, methods and descriptive results of a physiologic assessment of latino farmworkers: the California heat illness prevention study (CHIPS). *J Occup Environ Med*. 2017;59(7):649-658.
- Kwon J, Park HS, Kim S, Lee K. Impacts of gender, weather, and workplace differences in farm worker's gear. *Journal of Physiological Anthropology*. 2015;34:39-48.
- Hunt AP, Stewart IB. Calibration of an ingestible temperature sensor. *Physiol Meas*. 2008;29(11):N71-N78.
- Yamasue K, Hagiwara H, Tochukibo O, Sugimoto C, Kohno R. Measurement of core body temperature by an ingestible capsule sensor and evaluation of its wireless communication performance. *Adv Biomed Eng*. 2012;1:9-15.
- McKenzie JE, Osgood DW. Validation of a new telemetric core temperature monitor". *J Therm Biol*. 2004;29:605-611.

30. Crouter SE, Clowers KG, Bassett DR, Jr. A novel method for using accelerometer data to predict energy expenditure. *J Appl Physiol.* 1985;100:1324-1331. 25
31. ACGIH. 2008 TLVs<sup>®</sup> and BEIs<sup>®</sup>: threshold limit values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH: American Conference of Governmental Industrial Hygienists; 2008a.
32. Armstrong LE. Hydration assessment techniques. *Nutr Rev.* 2005;63: S40-S54.
33. Armstrong LE. Assessing hydration status: the elusive gold standard. *J Am Coll Nutr.* 2007;26(sup5):575S-584S.
34. Opplinger RA, Bartok C. Hydration testing of athletes. *Sports Med.* 2002;32:959-971.
35. Lemke B, Kjellstrom T. Calculating workplace WBGT from meteorological data: a tool for climate change assessment. *Ind Health.* 2012;50:267-278.
36. Rothfus LP. The heat index equation. *NWS Southern Region Technical Attachment SR/SSD 90-23.* Texas: Fort Worth; 1990.
37. Bernard TE, Iheanacho I. Heat index and adjusted temperature as surrogates for wet bulb globe temperature to screen for occupational heat stress. *J Occup Environ Hyg.* 2005;12(5):323-333. <https://doi.org/10.1080/15459624.2014.989365>
38. NOAA. National Weather Services. (2017a). <http://www.weather.gov/forecastmaps>
39. Vega-Arroyo The Role of Gender in Hydrating Practices of California Farmworkers.
40. NOAA (2017b) "Wet-bulb globe temperature." <http://www.weather.gov/tsa/wbgt>
41. Jackson LL, Rosenberg HR. Preventing heat-related illness among agricultural workers. *J Agromedicine.* 2010;15(3):200-215. <https://doi.org/10.1080/1059924X.2010.487021>
42. Shibasaki M, Crandall CG. Mechanisms and controllers of eccrine sweating in humans. *Frontiers in Bioscience (Scholar Edition).* 2010;2:685-696.
43. Kenefick RW, Sawka MN. Hydration at the work site. *J Am Coll Nutr.* 2007;26(sup5):597S-603S. <https://doi.org/10.1080/07315724.2007.10719665>
44. Armstrong LE, Casa D, Millard-Stafford M, Moran D, Pyne S, Roberts W. American college of sports medicine position stand. Exertional heat illness during training and competition. *Med Sci Sports Exerc.* 2007;39:556-572.
45. Carter R, III, Chevront SN, Williams JO, et al. Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Med Sci Sports Exerc.* 2005;37:1338-1344.
46. National Collegiate Athletic Association. Five-day acclimatization period, Divisions I-A and I-AA. In: NCAA Division I Manual. Indianapolis, IN, 2003, Rule 17.11.2.3.
47. Farmer FL, Slesinger DP. Health status and needs of migrant farm workers in the United States: A literature review. *J Rural Health.* 1992;8:227-234. <https://doi.org/10.1111/j.1748-0361.1992.tb00356.x>
48. Rao P. *Heat related illnesses: An occupational health concern for farmworkers.* Washington, D.C: Farmworker Justice and Migrant Clinicians Network; 2007. Retrieved from <https://www.farmworkerjustice.org/sites/default/files/documents/Heat20Related20Illnesses.pdf>

**How to cite this article:** Vega-Arroyo AJ, Mitchell DC, Castro JR, et al. Impacts of weather, work rate, hydration, and clothing in heat-related illness in California farmworkers. *Am J Ind Med.* 2019;62:1038-1046. <https://doi.org/10.1002/ajim.22973>