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# How Does Environmental Temperature Affect Farmworkers' Work Rates in the California Heat Illness Prevention Study?

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**Objective:** Estimate the association between environmental temperature (wet bulb globe temperature [WBGT]) and work rate over the course of a workday. **Methods:** Repeated-measures regression was used to identify characteristics impacting work rate in a cross-sectional study of Latino farmworkers. Minute-by-minute work rate (measured by accelerometer) and WBGT were averaged over 15-minute intervals. **Results:** Work rate decreased by 4.34 (95% confidence interval [CI], −7.09 to −1.59) counts per minute per degree Celsius WBGT in the previous 15-minute interval. Cumulative quarter hours worked (2.13; 95% CI, 0.82 to 3.45), age (−3.64; 95% CI, −4.50 to −2.79), and dehydration at the end of workday (51.37; 95% CI, 19.24 to 83.50) were associated with counts per minute as were gender, pay type (piece rate vs hourly) and body mass index ≥25 kg/m$^2$. The effects of pay type and body mass index were modified by gender. **Conclusion:** Increased temperature was associated with a decrease in work rate.

**Keywords:** environmental temperature, farmworkers, heat illness, work rate

## LEARNING OUTCOMES

1. Outline the importance of farmworkers' risk of heat-related illness.
2. Summarize the factors associated with changes in work rate among study participants.
3. Critically evaluate the role of task as a potential mediator of the effect of age on work rate among the study population.

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Farmworkers are at a high risk of heat-related illness (HRI), particularly as their peak work season, which includes strenuous bouts of outdoor labor, corresponds to high summer temperatures.[1,2,3] In an analysis of California Workers' Compensation claims during 2000 to 2017 data, the industry sector "Agriculture, Farming, Fishing, and Forestry" had the highest rate of HRI. In addition, the crop production industry was identified as a high-priority industry for intervention, with 41.1 claims per 100,000 workers.[4] An analysis of nationwide heat-related mortality cases reported to the US Bureau of Labor Statistics 2000 to 2010 found that the agricultural industry had the highest HRI mortality rate.[5] Between 2005 and 2021, 32% of the 502 fatal and catastrophic heat cases in California were among workers in the Agriculture, Forestry, Fishing, and Hunting industry. Of these cases, 94% were farmworkers.[6] However, these are likely to represent a significant undercount of the true number of HRI cases and mortalities, especially in industries such as agriculture where workers are less likely to be aware of their right to compensation or less willing to report injury and illness.[4,5,6] In addition to HRI morbidity and mortality, heat exposure is associated with increased injuries[7] and acute kidney injury[8] among farmworkers.

Farmworkers' exposure to high temperatures will intensify as a result of global climate change. The temperature in California is projected to increase between 5.6°F and 8.8°F by the end of the century, with the annual temperatures having already increased by greater than 1°F across most of the state.[9] In addition to increasing the risk for HRI, agricultural productivity is anticipated to fall as workers reduce work rate to cope with heat and shift to earlier and later working hours to avoid peak heat exposure.[10] Previous analyses found that male's work rate increased if they were paid by the piece, although there was not a similar effect for females. In addition, workers conducting multiple tasks, irrigators, males, and those paid by the piece had higher adjusted mean work rates and thus were likely at an increased risk of HRI on hot days.[11]

The California Heat Illness Prevention Study (CHIPS) is the first investigation of risk factors for heat illness using accelerometers to provide an objective measure of work rate. Core body temperature and environmental temperature were also measured. This analysis examines the association of ambient temperature and other factors with work rate using repeated-measures generalized linear models for autoregressive data. In addition, this analysis offers the benefit of assessing the relationship on a more granular level than previous analyses of CHIPS data, which used mean environmental temperature and work rate across the work shift.

## MATERIALS AND METHODS

Fieldwork for the cross-sectional CHIPS study was conducted in the summers of 2014 and 2015 throughout California's Central and Imperial Valleys. Bilingual, bicultural staff recruited a convenience sample of Latino farmworkers through farms and farm labor contractors (FLCs). Farmworkers participated for one daytime work shift. Detailed study methods have been reported previously.[3] The University of California, Davis Institutional Review Board approved the study protocols.

### Participation

Each worker completed an interviewer-administered questionnaire before and after work shift. To be eligible to participate, participants had to self-identify as Latino, be conversant in Spanish or English, be 18 years or older, and work outdoors for at least 5 hours. Workers were excluded if they spent extensive time driving or working in air-conditioned space, were pregnant, had an elevated body temperature at the start of their shift, or had gastrointestinal distress. Workers could refuse to answer any questions or withdraw from the study at any time. Participants who completed the full day of study activities were provided with a $50 gift card for their time and effort.

## Questionnaire Data

Participants responded to detailed questionnaires, including demographic information, pay/hire information, the sampling day's work experience, water and beverages consumption, and knowledge of HRI. Details of data cleaning have been reported elsewhere.[3,11]

A clothing inventory recorded all articles of clothing worn except underwear.[12] The constructed clothing scale ranged from 0 to 12, with a lower score corresponding to greater compliance with California's Occupational Safety and Health Standards Board's recommendations at the time of the study: wide-brimmed hat, light-colored, loose-fitting pants, and shirt with only one layer (Table 1).

## Anthropometric Data

Height was measured twice at the beginning of the work shift using a Seca Model 213 stadiometer (Seca GMBH & Co, Hamburg, Germany). The average of the two measures was calculated. Weight was measured twice preshift and postshift on a Seca Model 874 scale (Seca GMBH & Co) that was placed on a leveled board. Staff tried to ensure that the same clothing was worn preshift and postshift. The average of the two weights was calculated. Body mass index (BMI) was calculated using the preshift weight and height using the following formula: (preshift weight in kilograms) / (preshift height in meters squared). Participants were considered to be dehydrated if they lost 1.5% or more of their body weight across their work shift.[13]

## Physiological Data

Workers wore an Actical™ accelerometer (Actical Philips Respironics, Murrysville, PA) throughout the work shift. The accelerometer was attached to the worker's waist belt using both a Velcro band and zip ties. The accelerometer measured work rate at 1-minute intervals, resulting in counts per minute (cpm). Because of the transient nature of the accelerometer data, the counts per minute were merged into 15-minute increments. The averages over these 15-minute increments were then used for analysis. This allowed for data smoothing while still retaining the sensitivity needed to analyze any trends or correlations.

## Environmental Temperature Data

The wet bulb globe temperature (WBGT) was measured two ways: QUESTemp and HOBO. The QUESTemp 36 thermal environment monitor (Quest Technologies, Inc, Oconomowoc, WI) was set up on a 1.2-m tripod. As it was mobile, it provided the best measure of the local field conditions where participants were working. It was kept near the majority of workers and was not moved more than twice a day to ensure consistency. QUESTemp 36 has a temperature accuracy of ±0.5°C between 0°C and 120°C and a relative humidity accuracy of ±5% between 20% and 95%.[14] If QUEST data were not available, adjusted HOBO data were used. The HOBO U30 weather station (Onset Computer Corp, Bourne, MA) was set up on a 3-m tripod. As such, it was less mobile and provided ambient conditions at a stationary central location on each farm for the duration of data collection (1 to 5 days). Twenty-six subjects did not have QUEST data available; for these subjects, the HOBO was used. Fifteen subjects used a combination of the two, as QUEST data were missing for certain times that the subjects were working.

The QUEST collected WBGT at 1-minute intervals. The HOBO also collected environmental data at 1-minute intervals, but not WBGT. However, we were able to calculate WBGT using variables collected by the HOBO and the following equation:

$$WBGT = \left(T_a{}^* \; T_g{}^* \; T_d{}^* \; ws^* \; solar^* \; RH\right)$$

where $T_a$ = ambient temperature, $T_g$ = globe temperature, $T_d$ = dew point, ws = wind speed, solar = solar radiation, and RH = relative humidity. Wet bulb globe temperature was then averaged over the same 15-minute intervals used for averaging work rate.

## Statistical Analyses

Summary statistics are reported for variables of interest, such as pay type, clothing score, and BMI. $\chi^2$ Test and $t$ tests were used to compare males to females. All analyses were performed with SAS 9.4 (SAS Institute, Inc, Cary, NC). To account for the within-worker averaging of work rate and WBGT measurements over 15-minute intervals, we specified a linear regression model for autocorrelated repeated measures with the worker/quarter-hour intervals as the units of analysis, using PROC MIXED. Examined variables included various demographics and work-related attributes, specifically age, gender, BMI, dehydration status, clothing score, pay type (piece rate or hourly), and how long the subject had been at work. To estimate the effects of season and day, the month, year, and time of day were also considered. Variables that were not statistically significant ($P < 0.05$) were removed individually and then reevaluated for inclusion in the

**TABLE 1.** Clothing Inventory Scoring in California Heat Illness Prevention Study

| Article of Clothing | Scoring | Score Range |
|---|---|---|
| Headgear | 0: Wide-brimmed hat | 0–1 |
| | 1: Anything else (bandana(s), beanie, no head covering) | |
| Pants | 0: Light-colored | 0–2 |
| | 1: Dark-colored | |
| | 0: Loose-fitting | |
| | 1: Tight-fitting | |
| Tops | 0: Light-colored | 0–4 |
| Four possible: T-shirt, long-sleeve shirt, sweatshirt, jacket | 1: Dark-colored | |
| | 0: Loose-fitting | 0–4 |
| | 1: Tight-fitting | |
| | 0: One layer | |
| | 1: More than one layer | 0–1 |
| Total | | 0–12 |

CHIPS, California Heat Illness Prevention Study.

 

final model. Interactions tested were gender by pay type, gender by BMI, and age by BMI. Again, $P < 0.05$ was used to determine inclusion in the model. Wet bulb globe temperature, time worked since 4 AM, and age were centered around the mean.

## RESULTS

### Demographics

Over the two seasons, 587 farmworkers from 30 farms participated in the study. Approximately 50% of those recruited agreed to participate in the study. After data cleaning, 563 subjects (96%) were included in the final analysis presented in this article. Males comprised two-thirds of the population. Participants' ages ranged from 18 to 82 years, with a mean age of 38.5 years. The mean BMI was 29.1 kg/m$^2$ (95% confidence interval [CI], 28.7 to 29.5 kg/m$^2$). By the end of the workday, 67 workers (12%) had lost more than 1.5% of their body weight and thus were considered dehydrated (Table 2). Males and females did not differ significantly in pay type, age, or hours worked (quarter hours per subject). The majority of subjects were paid hourly (n = 440 [78%]), as opposed to being paid by the piece (n = 123 [22%]). Females had a higher average BMI than males ($P = 0.0085$). Males were more likely to lose more than 1.5% of their body weight during the day (16% vs 3%, $P < 0.0001$), a possible sign of dehydration, even though females had a higher (worse) clothing score on average (5.6 vs 4.4, $P < 0.0001$). The average WBGT ranged from 11°C to 43°C, with an average temperature of 25°C. Interestingly, males experienced a significantly higher temperature than females (25.2°C vs 24.8°C, $P < 0.0001$).

### Work Rates and Tasks

Each subject had an average of 25 usable quarter hours (or 6 hours 15 minutes) of data, after removing break and lunch times. The work rates over 15 minutes averaged 338 cpm. Females had a lower average work rate than males (251 vs 385, $P < 0.0001$, Table 2). Work rates varied widely by what task the subject was performing. Table 3 sorts 13 tasks by the median work rate of workers performing that task. Tasks covered a wide range of crops including tree nuts, stone fruits, melons, berries, tomatoes, grapes, corn, carrots, garlic, basil, cotton, chili peppers, cucumbers, and olives. Previous analyses have detailed tasks associated with specific crops.[11] Groundskeepers working at a land-grant university were included in the study as they had many similar responsibilities as other farmworkers, including tending grapevines and looking after flowering plants. Groundskeepers had the highest work rate, with a median of 703 cpm. At the other end, ground pruners had the lowest work rate with a median of 22 cpm. Sorting, packing, and supervising were all on the low end with medians of 46, 107, and 188 cpm, respectively. All other tasks had medians ranging from 225 to 411 cpm. The most common task was high harvesting, with 110 participants completing this task. It was also the second most intense task by work rate with a median of 411 cpm.

### Repeated-Measures Regression Modeling Results

Results of the repeated-measures analysis are shown in Table 4. As hypothesized, as temperatures measured as the 15-minute interval average WGBT increased, the average accelerometer cpm (work rate) in the next 15-minute interval decreased (estimate, −4.34, $P = 0.002$). Similarly, work rate decreased with age (estimate, −3.64; $P < 0.0001$). Conversely, average work rate in a given 15-minute interval increased over the work day (estimate, 2.13; $P = 0.0014$). Dehydration, or losing 1.5% or more of body weight over the work shift, was positively associated with work rate (estimate, 51.37; $P = 0.0018$). Although males recorded a higher work rate than females (Table 2), the relationship between gender and work rate was further complicated by significant interactions with both BMI and how a subject was paid (Table 5). Females had a lower work rate than males regardless of pay type or BMI. Among males, those paid by the piece had a higher work rate than those paid hourly regardless of BMI. Among males paid by the hour, those with a BMI ≥25 kg/m$^2$ had a lower work rate. Table 6 shows the work rate in cpm at three given temperatures, 22.1°C, 25.6°C, and 28.5°C, or Q1, Q2, and Q3 observed temperatures, respectively. In contrast to the other participants with steadily declining work rate as temperature increased, males paid hourly had the highest work rate at the middle temperature, 4565.5 cpm compared with 471.5 cpm and 444.0 cpm at 22.1°C and 28.5°C, respectively.

## DISCUSSION

### Temperature, Piece-Rate Pay, and Work Rate

The analysis presented in this article shows work rate decreasing as WBGT increases in the previous 15-minute interval, as well as a positive association between piece-rate pay and work rate. Conversely, work rate increases over the course of the shift beginning at 4 AM, as the heat of the day increases. It is possible that the choice of statistical methods in this analysis does not capture a nonlinear effect where work rates decrease or increase more slowly at hotter temperatures, which would explain the apparent conflict between work

**TABLE 2.** Demographic and Work Characteristics of CHIPS Participants

| Characteristics | Overall n = 563 n (%) | Male n = 370 n (%) | Female n = 193 n (%) | $\chi^2$ P |
|---|---|---|---|---|
| Pay type | | | | 0.2670 |
| Piece rate | 123 (22) | 86 (23) | 37 (19) | |
| Hourly | 440 (78) | 284 (77) | 156 (81) | |
| Dehydrated | 67 (12) | 61 (16) | 6 (3) | <0.0001 |
| | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | ***t* Test *P*** |
| Age | 38.5 (12.1) | 38.48 (10.8) | 38.7 (10.8) | 0.8404 |
| BMI, kg/m$^2$ | 29.1 (4.7) | 28.7 (4.6) | 29.8 (4.6) | 0.0085 |
| Clothing score | 4.8 (1.7) | 4.4 (1.4) | 5.6 (1.9) | <0.0001 |
| No. of quarter hours per subject | 25.3 (7.9) | 24.9 (8.1) | 26.1 (7.4) | 0.0979 |
| **Quarter-Hour Measurements** | **n = 14,245** | **n = 9215** | **n = 5030** | |
| | **Mean (SD)** | **Mean (SD)** | **Mean (SD)** | |
| Work rate (cpm, average of previous quarter hour) | 337.5 (361.8) | 385.0 (373.7) | 250.6 (321.2) | <0.0001 |
| Wet bulb globe temperature (°C, average of previous quarter hour) | 25.1 (4.6) | 25.2 (4.7) | 24.8 (4.3) | <0.0001 |

BMI, body mass index; CHIPS, California Heat Illness Prevention Study; cpm, counts per minute.

 

**TABLE 3.** Farmworker Tasks Sorted by Work Rate

| Task | n | Male, n (%) | Age Mean (SD), y | Work Rate Median (Min–Max) | Description |
|---|---|---|---|---|---|
| Ground pruning | 31 | 6 (19) | 41 (13) | 22.3 (0–389.9) | Removing, trimming, and thinning plants. Motions include walking, standing, and bending with repetitive hand movements. |
| Sorting | 49 | 13 (27) | 42 (14) | 45.7 (0.7–3184.3) | Dividing harvested crop by grade/size. Motions include standing with repetitive arm and hand movements. |
| Packing | 23 | 7 (30) | 39 (10) | 106.9 (0–597.4) | Loading and unloading boxes. Motions include sitting, standing, assembling boxes, and packing and moving boxes. |
| Supervising | 18 | 14 (78) | 41 (12) | 187.9 (7.1–558.3) | Overseeing workers and other tasks not directly working on crops. Motions include driving, walking, standing, and communicating with farmworkers. |
| Carrying | 8 | 8 (100) | 37 (12) | 225.1 (10.7–1103.6) | Moving ready-packed crop or other materials. Motions include bending, walking, and lifting bulky materials. |
| Harvesting, low | 60 | 38 (63) | 34 (13) | 228.0 (6.2–665.7) | Harvesting into a container either attached to body or carried. Motions include walking, standing, bending, and reaching. |
| Pruning, high | 73 | 33 (45) | 37 (11) | 280.9 (13.6–1229.9) | Removing, thinning, training branches, and vegetation. Motions include walking and lifting tools above the waist with repetitive hand motions. |
| Multiple tasks | 70 | 67 (96) | 39 (13) | 289.9 (0–2645.3) | Combination of other tasks |
| Irrigating | 71 | 71 (100) | 39 (11) | 290.3 (0–1652.4) | Carrying, lifting, and setting irrigation pipes, opening and adjusting water valves, and reeling in irrigation lines. Motions include walking, bending, and squatting. |
| Hoeing/raking | 29 | 13 (45) | 35 (11) | 340.3 (10.3–1009.1) | Using a hoe or rake to weed and remove plants. Motions include walking, hunching over, and dragging materials with the tools. |
| Shoveling | 9 | 9 (100) | 39 (12) | 367.5 (6.1–589.2) | Using a shovel to lift, dig, and move material such as soil, nuts, or hulls. Motions include walking, standing, and shoveling. |
| Harvesting, high | 110 | 81 (74) | 38 (11) | 411.3 (7–1766.2) | Hand harvesting, usually stone fruit. Motions include walking, carrying ladder, reaching, placing crop into container worn on the worker, and carrying to a bin. |
| Groundskeeping | 12 | 10 (83) | 50 (11) | 702.6 (80.3–2219.1) | Planting and maintaining vegetation not grown as crops on university campus including athletic fields, lawns, trees, shrubs, flowerbed, etc. Motions include driving open air vehicles, mowing, pruning, planting, and weeding. |

rates increasing throughout the day but decreasing with rising WBGT. A previous analysis of work rate and environmental temperature using these data reflected that workers paid by the piece had a higher work rate than workers paid hourly at lower temperatures but greater than 26.6°C; there was an inverse association between work rate and piece-rate pay.[15] The finding by Pan et al[15] could indicate that, although piece-rate pay is associated with HRI[16] and disincentivizes rest and hydration breaks,[17] piece-rate workers have more flexibility to adjust their work rate at the highest temperatures. This could be one reason why males paid hourly had a higher work rate at 25.6°C.

The first-quarter-hour temperature of the day was negatively correlated with the overall average of quarter-hour-work rates, but it did not reach statistical significance ($r = -0.07$, $P = 0.12$, data not shown). For the workers in this analysis, maximum daily temperatures ranged from 22°C to 44°C, with an average daily max of 31°C. Imperial's historical (2000 to 2020) average maximum summer temperatures ranged from 39 to 47°C, and Fresno's historical (2000 to 2020) average maximum summer temperatures ranged from 33°C to 42°C.[18,19] Given the wide geographic coverage of participating farms, the maximum daily temperatures seen in this study are reasonable.

The average 15-minute work rate of 338 cpm is considered a low-intensity work level.[11] Other industries, such as general construction, are similar to farm work with less intensity and shorter bursts of moderate physical activity.[20] In contrast, occupations such as deep mining and active firefighting have both mean and peak energy expenditures in moderate to higher levels of intensity.[21,22]

In an analysis with core body temperature, Langer et al[23] found a positive association between mean work rate (but not piece-rate pay) and elevated maximum core body temperature during the work shift when adjusted for ambient WBGT. Other analyses using data from this study have found a positive association between acute kidney injury and piece-rate pay,[8,24,25] as well as work rate.[25] Another previous analysis found piece-rate pay was associated with an increase in work rate for men but not women; the same analysis considered the median

**TABLE 4.** Repeated-Measures Model* Association Between Mean Work Rate in Counts per Minute and Worker Characteristics

| Covariate | Estimate | 95% CI | *P* |
|---|---|---|---|
| Wet bulb globe temperature centered around 25°C (mean, 0.06°C) | −4.34 | −7.09 to −1.59 | 0.002 |
| Quarter hours worked since 4 AM centered around 29 (11:15 AM) | 2.13 | 0.82 to 3.45 | 0.0014 |
| Gender (male reference) | | | <0.0001 |
| Pay type (hourly reference vs piece rate) | | | <0.0001 |
| Female × piece rate pay interaction | | | 0.0011 |
| Age centered around 38 y (mean, 0.5 y) | −3.64 | −4.50 to −2.79 | <0.0001 |
| BMI (BMI <25 reference vs BMI ≥25 kg/m$^2$) | | | 0.0004 |
| Female × BMI ≥25 kg/m$^2$ interaction | | | 0.0021 |
| Dehydration | 51.37 | 19.24 to 83.50 | 0.0018 |

BMI, body mass index; CI, confidence interval.

*Regression model for repeated-measures data with worker quarter-hour intervals as units of analysis was fit using SAS PROC MIXED with within-subject first-order autoregressive structure for residuals. Estimated autocorrelation was 54%.

 

**TABLE 5.** Repeated-Measures Model Estimated Pairwise Contrasts in Mean Work Rate for Gender/Pay Type/BMI Subgroups; Reference Group Males Paid Hourly With BMI <25 kg/m²

| Gender | Pay Type | BMI, kg/m² | Estimate | 95% CI | P |
|---|---|---|---|---|---|
| Female | Piece rate | <25 | −160.63 | −229.4 to −91.9 | <0.0001 |
| Female | Piece rate | ≥25 | −119.63 | −172.9 to −66.3 | <0.0001 |
| Female | Hourly | <25 | −190.05 | −248.0 to −132.1 | <0.0001 |
| Female | Hourly | ≥25 | −149.04 | −183.8 to −114.3 | <0.0001 |
| Male | Piece rate | <25 | 126.02 | 93.0 to 159.0 | <0.0001 |
| Male | Piece rate | ≥25 | 70.82 | 22.9 to 118.7 | 0.0038 |
| Male | Hourly | ≥25 | −55.20 | −85.7 to −24.7 | 0.0018 |

BMI, body mass index; CI, confidence interval.

WBGT and mean work rate across the shift and estimated a decrease in work rate of 13.5 mean cpm per degree Celsius increase in WBGT over the entire shift.[11]

In other studies of temperature, pay type, and work rate in agriculture, work rates declined with increasing temperature. Florida crop workers reduced work rates (measured with an accelerometer secured at the iliac crest as in this study) with increasing WBGT.[26] A Washington study found a positive association between piece-rate pay and self-reported symptoms of HRI.[16] Florida experiences significantly higher humidity than California, and other studies showing associations between environmental heat and decreased productivity[27] or kidney disease[28] are largely conducted in the hot and humid climates of India, Sri Lanka, and Central America. The WBGT experienced by CHIPS participants is generally lower, and in addition, the work rate lower, than what is seen in these other studies.

## Dehydration

The strongest association with work rate in the multivariate model was dehydration measured at the end of the shift, with an estimate of 55.3 (95% CI, 23.1 to 87.4) greater cpm in each 15-minute interval among workers who were dehydrated. The positive association between dehydration and work rate may be due to greater fluid loss from sweating among more active workers. The higher work rate could also result from taking fewer breaks to hydrate. However, in a separate analysis by Langer et al,[23] participants in this study were found to drink more water in higher temperatures but not in sufficient quantity to prevent dehydration. Dehydration can lead to elevated core body temperatures,[29] as well as blood volume depletion that can lead to kidney damage, which was seen in the CHIPS study.[8,24,25]

## Sex, BMI, Piece-Rate Pay, and Work Rate

When considering interactions between sex, BMI (less than 25 vs 25 kg/m² or greater), and pay type (piece rate vs hourly), complex relationships between these factors were revealed (Table 5). Previous analyses of these data have shown interactions between work rate and both sex and pay type, with piece-rate pay increasing work rate only among men.[11] In this analysis, the effect of piece-rate pay on work rate among men was larger among those with a BMI <25 kg/m². In all cases, women had a lower work rate, but the reduction in work rate was of a lesser magnitude for both piece-rate and hourly paid women who had a BMI greater than 25 kg/m².

## Tasks

Participants in the study performed many individual tasks, which were grouped by type (Table 3). In addition to the average work rate varying by task, the average age of workers and pay type (piece rate vs hourly) differ by task; tasks also change throughout the season. This complicates the relationships with environmental temperature because tasks shift as average temperatures rise and fall seasonally. Although we did not have the power to do a full analysis by task, we were able to look at them descriptively with relation to the mentioned variables.

Study subjects had an overall mean age of 38.5 years. The 60 workers doing the low harvesting (hand harvesting into a container on the body or carried) tasks were the youngest, with an average age of 34.2 years. At the other end of the spectrum, the 12 groundskeepers were the oldest, with an average age of 49.5 years. Whereas groundskeeping had the highest work rate, other tasks with an older population had lower average work rates and included ground pruning, sorting, packing, shoveling, supervising, and irrigating.

Tasks evolve as the farming season progresses. Tasks in June include irrigating, hoeing/raking, low harvesting, and packing, among others, whereas October tasks consisted of only high harvesting and carrying. Forty-eight percent of the irrigation was done in June as plants are being established. Ninety-three percent of the high harvesting was done in October as this is when the fruit trees ripen. Within our subject population, 90% of all ground pruning occurred in July, whereas 78% of shoveling occurred in September, and 63% of tree pruning occurred in August.

Task also influences how subjects were paid, as many tasks would not make sense to be paid by the piece. Fifty-five percent of piece-rate workers were high harvesters; another 17% were low harvesters, and 16% pruned trees. Conversely, every groundskeeper, irrigation worker, and shoveler were paid hourly. Subjects working in groundskeeping, irrigating, and shoveling also tended to be older than working concentrating on other tasks; subjects working in trees, either pruning or harvesting, tended to be younger and paid by the piece.

## Implications

Educational campaigns for farmworkers and supervisors have been shown to increase workers' knowledge of best practices for HRI prevention.[30,31] However, the evidence that they result in empirical measures of decreased HRI or dehydration is weaker.[32] Heat-related illness may also be underrecognized by both workers and clinicians,[33] and workers may need targeted interventions to recognize symptoms of HRI and learn appropriate first aid.[34] It also remains unquantified how effective the existing California HRI prevention standard is to date,[23] with more research needed to target further policy changes. Current HRI prevention interventions are aimed at the farm or worker level, but as the effects of climate change grow to impact more and more workers, higher-level structural interventions including climate change mitigation will be necessary to protect both worker health and food production capacity.[35]

## Strengths and Limitations

The CHIPS study's main strengths are the large sample size, with diverse farms, crops, and geography throughout California's Central Valley. In addition to being the first study to collect objective physiological data on farmworkers, this analysis provides a more nuanced examination of both the accelerometer data and environmental temperature. Rather than using a single average to represent the entire day as in previous analyses, we used work rate in quarter-hour increments and a corresponding WBGT from the previous quarter hour. However,

**TABLE 6.** Impact of Temperature on Work Rate for Participants With BMI < 25

| | | Work Rate (Cpm) | | | |
|---|---|---|---|---|---|
| Quartile | Temperature (°C) | Female/ Piece Rate | Female/ Hourly | Male/ Piece Rate | Male/ Hourly |
| 1 | 22.1 | 311.4 | 281.5 | 597.0 | 471.5 |
| 2 | 25.6 | 296.4 | 266.5 | 582.6 | 4565.5 |
| 3 | 28.5 | 284.0 | 254.0 | 570.1 | 444.0 |

 

these data come with limitations. First, the convenience sample based on recruitment at the worksite may have in resulted including workers from farms that were more likely to follow occupational health regulations. The accelerometers may undercount true work rate by not registering minor body motions, especially motions that were focused in the hand/arm area. This may have considerably affected results for subjects who were lying down to pick strawberries, subjects who were sorting and packing, and other similar activities; ground pruning, sorting, and packing had the lowest accelerometer ratings.

Obesity or elevated BMI is associated with a reduced heat stress tolerance. The underlying mechanism is assumed to be body heat retention,[36] but the potential for confounding by other factors is unexplored, and the value of BMI as a measure of adiposity is limited.[37] The relationship between BMI and percentage of body fat differs for men and women, potentially explaining at least part of the interaction between sex and BMI we see in this analysis.

There was a great variety of tasks done among subjects, allowing for a better sense of the "average" farmworker. However, it made analysis comparing tasks underpowered. There may be differences among tasks by gender, age, and time of year, all of which in turn may affect work rate. However, we were unable to explore these possible differences because of a limited number of subjects in each task category and the high number of differing categories. Although there may be differences between the 30 participating farms due to work culture, we expect these to be minimal given the heterogeneity of crops and tasks, FLCs moving around frequently, carpool with different groups, and workers having different days on/off.

## CONCLUSIONS

This is the first study to directly measure work rate levels, providing a level of detail and objectivity beyond that available in questionnaire-based studies. Compared with previous analyses of CHIPS data, this article presents a more nuanced approach by assessing the repeated-measures work rate and temperature data longitudinally rather than compressing it to one mean value per workday. The chief finding—that work rate decreases as WBGT increases—is consistent with other analyses of CHIPS data, as well as other studies of the subject. In addition, interactions between sex, BMI, and type of pay were identified.

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