Evaluation of Buller Estimated Core Body Temperature Algorithm Accuracy and Application in Agricultural Workers

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Abstract

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Background: Adverse health effects of extreme heat in occupational settings are substantial, particularly among outdoor workers who perform physical labor. Core body temperature (CT) is a critical indicator of heat strain. Excessive increase in CT negatively affects physical and cognitive performance and can lead to heat exhaustion or heat stroke. The most accurate locations for measuring CT are the rectum or the esophagus, but the invasiveness of these measurements makes it impractical in field settings. Ingestible pills make it possible to monitor deep body temperatures in field settings. However, these are costly to use on a regular basis, are sensitive to food and fluid intake, and may not be acceptable to all people. Thus, there is a need to be able to non-invasively measure, in real time, accurate CT. Buller et al. developed an algorithm to estimate CT based on heart rate and baseline temperature.

Objective: There has been little study of the accuracy of the Buller algorithm among working populations such as agricultural workers in field settings or among females and older workers. The overall goal of this project was to assess and apply the Buller algorithm in a field setting among agricultural workers.

Aim 1 evaluated the accuracy of the Buller algorithm for estimating CTs and Physiological Strain Indices (PSIs), compared to ‘gold standard’ CT sensor data from an ingestible pill, in a field setting among agricultural workers.

Aim 2 examined the effectiveness of a heat prevention intervention by comparing CT and PSI outcomes estimated using the Buller algorithm between the intervention and comparison groups. We expect the CTs and PSIs in the intervention group to be lower than in the comparison group.

Methods: The first aim of this project leveraged ‘gold standard’ ingestible CT sensor data and Buller algorithm-derived CT estimates that have both been collected across one work shift in 2015 among 35 Washington farmworkers. The Bland-Altman method was used to assess how well the observed CT from the ingestible pill and the estimated CT from the Buller algorithm agreed. Analyses were performed both using 37.1°C and also measured aural temperature +0.27°C as the baseline temperature for the Buller algorithm. A similar analysis for PSI was performed.

The second aim of this project built upon data collected as part of a 2019 randomized heat intervention study among 75 Washington farmworkers. In this parent study, the intervention group was trained on heat safety and health precautions and supervisors were provided with a decision support application aimed at heat illness prevention. Workers in the intervention group and in the comparison group, which did not receive heat prevention training or the heat application, were evaluated approximately monthly during the summer harvest season to measure heat strain, and the maximum work shift PSI was calculated using the estimated CT from the Buller algorithm. The association between max work shift PSI and group status was assessed using linear mixed effects models with random effects for workers.

Results: For Aim 1, the overall CT bias was -0.14°C with LoA of ±0.76 when 37.1°C was used as the baseline temperature in the Buller algorithm. When measured aural temperature +0.27°C was used as the baseline temperature, the overall bias was -0.085°C with LoA of ±0.90. The PSI had a bias and LoA of -0.29 ±1.59 when the baseline temperature was 37.1°C. When aural temperature +0.27°C was used as the baseline temperature, the overall bias for PSI was -0.15 with LoA of ±1.42.

For the heat intervention study in Aim 2, the mean (standard deviation) of the maximum shift PSI for all participants was 4.61 (1.49) and 4.30 (1.53) for the comparison and intervention groups, respectively. The unadjusted linear mixed effects model effect estimate of group status (intervention vs. comparison) with max PSI was -0.26 (95% confidence interval [CI]: -0.84, 0.31). After adjustment for farm and ambient maximum shift heat index, the effect estimate was -0.13 (95% CI: -0.50, 0.25).

Conclusion: Agricultural workers work under heat stress and are at risk for heat-related illness. The Buller algorithm, based only on heart rate and a baseline core temperature, was independently validated. When the Buller algorithm was applied to evaluate the effectiveness of the heat intervention study, intervention versus comparison group status was associated with a lower max PSI, but this was not statistically significant. Further analyses are needed to assess for potential effect modification, including by task type and exertion. The Buller algorithm may be a promising method for estimating CT and PSI in field conditions for research purposes.

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DISCUSSION

Introduction

From 1992-2006, a total of 423 workers died from exposure to environmental heat; 68 (16%) of these workers were crop workers. Heat-related deaths for crop workers averaged 0.39 per 100,000 workers, compared to 0.02 for all US civilian workers (*Heat-Related Deaths Among Crop Workers - United States, 1992-2006*, n.d.). Deaths from heat-related illness are preventable. Outdoor workers who perform heavy physical labor are especially at risk for adverse health effects caused by heat exposure.

Risk factors for occupational heat-related illness include absence of shade, distance to beverages and restrooms, and payment type (e.g. piece-rate payment vs hourly wage which incentivizes workers to work harder and faster and minimize breaks). Personal risk factors for heat-related illness include chronic diseases, lack of acclimatization to heat, non-breathable clothing, certain medications, and certain beliefs about treatment and prevention of heat illness (Lam et al., 2013) (Jackson and Rosenberg, 2010).

Core body temperature (CT) is a critical indicator of heat strain. Excessive increase in CT negatively affects physical and cognitive performance and can lead to heat exhaustion, heat stroke, or even death. The most accurate locations for measuring CT are the rectum or the esophagus, but the invasiveness of these measurements makes it difficult to use outside the clinical setting. Ingestible pills, which transmit the temperature to an external receiver as the capsule travels through the digestive tract, make it possible to monitor deep body temperatures in field settings (O'Brien et al., 1998). However, these are costly to use on a regular basis, are sensitive to food and fluid intake (Wilkinson et al., 2008), and may not be acceptable to all people.

Over the years, various methods have been devised to predict CT with less invasive methods. For example, heart rate, ambient temperature along with the individual's height, weight, and clothing (Yokota et al., 2008); skin temperature, heart rate, and respiration rate (Richmond et al., 2015); and skin temperature and heat flux (measured at several sites) along with heart rate (Niedermann et al., 2014) (Eggenberger et al., 2018) have been used to predict CT. While all these methods are less invasive, they require multiple parameters. An ideal model would have reasonable accuracy and as few parameters as possible and would be cost efficient, practical, and field expedient.

Thus, there is a need to be able to non-invasively measure, in real time, accurate CT with as few parameters as possible. The Buller algorithm uses only sequential heart rate and baseline body temperature to estimate CT (Buller et al., 2013).

The physiological reason that sequential heart rate informs CT estimates is that heart rate increases with work, which causes the body to heat up and CT to rise. Heart rate also helps with heat dissipation. In order to dissipate heat, blood vessels near the skin dilate. Thus, heart rate accelerates to increase blood flow to muscles to help with the work needed to be performed and to increase peripheral blood flow to allow dissipation of the heat generated.

Algorithm Background and Validation Studies

The Buller algorithm uses an extended Kalman filter and was developed using field data from 17 male US Army soldiers (age = 23 ± 4 years) with core temperatures ranging from 36-40°C. The algorithm is initialized with a baseline core temperature (CT_0) and updated with heart rate at one-minute intervals. CT_0 can be measured or assumed to be 37.1°C. Showers et al. found that it was important not to include the first 30 minutes of data after the initialization process so that the temperature estimates were not unfairly influenced by CT_0 (Showers et al., 2016). Buller et al. also evaluated the accuracy of this algorithm on 82 male soldiers and one female soldier in four laboratory settings (testing various environmental conditions, hydration states, clothing, and acclimation states) and five field settings with temperature ranging from 9-47°C and relative humidity ranging from 9-95%. The data contained over 52,000 CT observations, with an overall bias of -0.03 ± 0.32°C with the Limit of Agreement (LoA) = ± 0.63°C. The overall weighted root mean squared error (RMSE) was 0.30 ± 0.13°C. Buller reported literature comparisons of esophageal and rectal methods average LoAs of ±0.58°C (Buller et al., 2013).

The algorithm was also evaluated by the developers in a study of military first responders wearing personal protective equipment in three different CBRNE (chemical, biological, radiological, nuclear, or explosive) training events. There were 25 male and 2 female volunteers (age: 30 ± 6 years). The overall bias was 0.028°C and RMSE was 0.218°C with LoA ± 0.488°C (Buller et al., 2015)

Heat Strain and the Physiologic Strain Index (PSI)

Heat stress is the effect of both body heat generated internally by muscle use as well as external heat imposed by the environment. Heat strain is the body's overall physiological response to heat stress. Acclimatization is an individual's physiological adaptation to heat stress and protects that individual from heat strain. Moran et al. developed a physiological strain index to categorize heat strain. The severity of heat strain is expressed on a scale from 0-10 with five as "moderate" heat strain, seven as "high" heat strain, and 10 as "very high" physiological strain, as shown in Figure 1 (Moran, Shitzer, & Pandolf, 1998). Evaluation of heat strain in our study was performed using the physiological strain index.

Figure 1. Calculated physiological strain index (PSI) using the equation $PSI=5(Tx - T0)*(39.5-T0)-1+5(HRx-HR0)*(180-HR0)-1$, where Tx is current core temperature, T0 is baseline core temperature, HRx is current heart rate, and HR0 is baseline heart rate. Source: Moran, 1998

PSI	Physiological Strain
0	none
1	minimal
2	
3	low
4	
5	moderate
6	
7	high
8	
9	very high
10	

Study Goals, Specific Aims, and Hypotheses

There has been little study of the accuracy of the Buller algorithm among working populations such as agricultural workers in field studies or among females and older workers. The overall goal of this project was to assess and apply the Buller algorithm in a field setting among agricultural workers.

This project leveraged 'gold standard' ingestible CT sensor data and Buller algorithm-derived CT estimates that have both been collected across one work shift in 2015 among 35 Washington farmworkers. This project also built upon data collected as part of a 2019 heat intervention study among 75 Washington farmworkers. In this parent study, the intervention group was trained on heat safety and health precautions and supervisors were provided with a decision support application aimed at heat illness prevention. Workers in the intervention group and in the comparison group, which did not receive heat prevention training or the heat application, were evaluated approximately monthly during the summer harvest season to measure heat strain. We performed a secondary analysis of the 2015 data and analyze the 2019 data to achieve the following Specific Aims:

Aim 1 evaluated the accuracy of the Buller algorithm for estimating CTs and PSIs, compared to 'gold standard' CT sensor data, in a field setting among agricultural workers.

Aim 2 examined the effectiveness of the heat prevention intervention by comparing CT and PSI outcomes estimated using the Buller algorithm between the intervention and comparison groups. We expected the CTs and PSIs in the intervention group to be lower than in the comparison group.

An accurate, real-time measure of CT is vital for effectively and efficiently monitoring and managing workers in hot environments. Early detection of rising CTs can enable early implementation of cooling strategies to prevent heat-related illness. Our results provide valuable information that may lead to better protection of workers who labor in the heat now and in the future with climate change.

Methods

Specific Aim 1: Validation of the Buller Algorithm

Data from 35 farmworkers in Washington state for one work shift on a summer day in 2015 were analyzed (see Table 1 in Appendix A). A convenience sample of orchards and adult (age 18 or older), piece-rate (paid by the amount of fruit harvested) tree-fruit harvesters from central/eastern Washington were recruited through University of Washington (UW) Pacific Northwest Agricultural Safety and Health Center contacts in 2015. Forty-six harvesters (34 during August pear harvest and 12 during September apple harvest) from six orchards (five pear orchards and one apple orchard) participated for one work shift each. Study procedures were reviewed and approved by the UW Institutional Review Board, and participants provided informed consent prior to participation.

Workers' core body temperatures and heart rates were monitored using CorTemp™ sensors (HQ Inc; Palmetto, FL) and Polar® chest band monitors (Polar Inc; Lake Success, NY), respectively. CorTemp™ sensor systems consist of small FDA registered and cleared (510K, No. 880639) ingestible thermometer 'pills.' Continuous core temperature and heart rate data were wirelessly transmitted to data recorders worn by workers. Heart rate and core temperature data were collected every 20 seconds. Baseline body temperatures were measured using tympanic thermometers (Braun; Kronberg, Germany). Ambient wet-bulb globe temperatures (WBGTs) were also measured using a hand-held WBGT monitor (Extech HT30 WBGT Meter, Extech Instruments; Nashua, NH) near individual workers approximately every one to three hours. The mean (standard deviation) maximum WBGT during participants' work shifts was 27.9°C (3.6°C) in August (range: 22.0°C–33.1°C) and 21.2°C (2.0°C) in September (range: 19.0°C–22.9°C) (Quiller et al., 2017).

Analysis

Sequential data was first trimmed to match work shift times. Heart rate values below 40 bpm and above 200 bpm and CT data below 34°C and above 42°C were excluded. One-minute average values were computed, and data were trimmed to remove the first 30 minutes of work. Participants with substantial amounts of missing data, measured gastrointestinal temperatures dipping below 36.5°C, and more than ten minutes of missing consecutive heart rate and CT data were excluded from the analysis. Eleven participants of the original 46 were excluded, resulting in 35 participants included Aim 1 analyses. A default baseline CT of 37.1°C was used in the primary analysis. In a secondary analysis, morning pre-work tympanic temperature measurements were used to impute baseline core body temperature values after applying an adjustment factor of +0.27°C to account for differences between core temperature and tympanic temperature (Huggins et al., 2012).

Estimated CT was computed using baseline CT and sequential heart rate using the Buller algorithm (Buller et al., 2013). Estimated CT was compared to observed (gastrointestinal) CT. In a secondary analysis, we computed the Physiological Strain Index (PSI) using the equation:

$$PSI = 5 \cdot \frac{HR - HR_0}{180 - HR_0} + 5 \cdot \frac{CT - CT_0}{39.5 - CT_0} \quad (1)$$

where HR is the heart rate, HR_0 is the baseline heart rate, CT is the core temperature and CT_0 is the baseline core temperature (Moran et al., 1998). As resting HR was not consistently collected, we imputed resting HR values using a regression equation from 2019 field data in a similar population modeling relationship between average of first five minutes of heart rate and measured resting heart rate measurements. We compared PSI using estimated CT to PSI using observed CT.

Bland-Altman method

The Bland-Altman method was used to assess the accuracy of the Buller algorithm for CT (Bland and Altman, 1986). This method assessed how well the observed CT from the ingestible pill and the estimated CT from the Buller algorithm agree. A similar analysis for PSI was performed.

The Bland-Altman method plots the difference (estimated - observed) on the y axis and the average of the observed and estimated CT values on the x axis (alternatively, the gold standard values can be plotted on the x axis). Bias is calculated as the mean of the differences. A limit of agreement (LoA) is calculated as the bias ± 1.96 x SD of the differences. 95% of all the estimates should fall within the LoA. The overall bias (including data from all the workers) was calculated and stratified by males and females and stratified by August (pear) vs. September (apple) harvest. Biases, RMSE, and MAE values were calculated for each individual.

The root mean squared error was calculated using this equation:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{N}(Temp\ Obs - Temp\ Est)^2}{N}}$$

Mean absolute error was calculated using this equation:

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n} | x_i - x |$$

where MAE is the mean absolute error, n is the number of errors, X is the estimated CT and X_i is the gastrointestinal CT.

Algorithm accuracy was depicted using scatter plots, Bland-Altman plots, and histogram of errors plots. A bias, RMSE, and MAE were calculated for each subject. These plots were created using 1) 37.1°C and 2) aural temperature +0.27°C as the baseline temperature in the Buller algorithm.

The PSI was calculated using observed and estimated core temperatures. An overall bias, LoA, RMSE, and MAE were calculated. The PSI calculations used: 1) 37.1°C; and 2) aural temperature +0.27°C as the baseline temperature.

Specific Aim 2: Heat Intervention

We analyzed data from a parallel, comparison, group intervention study that aimed to evaluate the effectiveness of a Heat Education and Awareness Tools (HEAT) intervention, consisting of worker training and a supervisor heat awareness application, on reducing adverse heat health effects for agricultural workers.

Eighty-seven farmworkers from eastern and central Washington State (WA) were recruited during the summer of 2019 from two large growers and two small growers (the small growers were owned by brothers) that agreed to participate in the study (Table 2 in Appendix B). Agricultural workplaces were recruited using various approaches, including through contacts of the UW Pacific Northwest Agricultural Safety and Health Center's research staff and listserv emails and through central and eastern WA agricultural organizations (e.g. Washington State University's AgWeatherNet weather station program). Farmworkers who were 18 years or older, planned to work in an agricultural field during the summer season (and spoke Spanish or English) and their supervisors were eligible to participate. Study procedures were reviewed and approved by the UW Institutional Review Board, and participants provided informed consent prior to participation.

Crews were randomly assigned to the intervention or comparison group. The intervention group received HEAT training, which addresses individual, workplace, and community level factors for heat health.

The supervisors in the intervention group received a HEAT awareness mobile application that supports decisions about workplace heat prevention and training on how to use it. The comparison group was offered a non-HEAT training. Physiological monitoring for heat strain was conducted approximately monthly at the worksite during the summer season. After the summer season, workers in the comparison group were offered a delayed HEAT training. For full details about the HEAT training and the HEAT awareness application see Appendix C.

Analysis

Of the 87 total recruited workers, 78 farmworkers completed at least one field monitoring day. Three more workers were excluded because they had less than 2 hours of heart rate data, for a total of 75 farmworkers. There were 38 participants in the comparison group and 37 in the intervention group (Table 3).

Each participant had a field monitoring day approximately one time per month. We initially tried to monitor participants for two consecutive days, resulting in 28 participants having two field monitoring dates in June. Due to burden on staff, we reduced this to one day per participant per month. Participants at the small farms were not enrolled until the end of June, so their first field monitoring day was in July. One participant at worksite B had two field monitoring dates in August, so they have a total of 5 days. The total potential number of participant-days across all sites was 246. There was a total of 22 participant-days missed due to vacations, injuries, illnesses, and unknown reasons. 23 participant-days had trouble downloading or did not log heartrate. Eight heart rate files had a duration under 2 hours, leaving a total of 193 participant-days.

Sequential data were first trimmed to match work shift times. Heart rate values below 40 bpm and above 200 bpm and CT data below 34°C and above 42°C were excluded. One-minute average values were computed, and data were trimmed to remove the first 30 minutes of work. Participants with less than two hours of data were excluded.

Table 3 Summary of Participant Inclusion and Exclusion by Crew

Crew	Description	Assignment	Number enrolled and consented	Number with one field monitoring day	Number dropped due to data less than 2 hours	Total number of farmworkers included in Aim 2	Total potential participant-days
A	Large - GG	Intervention	14	14	0	14	56
B	Large - GG	Comparison	14	14	0	14	57
C	Large - SM	Comparison	19	17	1	16	51
D	Large - SM	Intervention	17	16	0	16	48
E	Small	Intervention	13	8	1	7	16
F	Small	Comparison	10	9	1	8	18
TOTAL			87	78	3	75	246

The primary outcome was heat strain, the body's physiological response to heat stress. Heat strain was calculated using baseline and continuous heart rate and a baseline aural temperature approximately once per month. Continuous heart rate was measured using heart rate chest band monitors (Polar® chest band monitors; Polar Inc; Lake Success, NY) worn by participants throughout their work shift. Researchers recorded baseline aural temperatures (Braun; Kronberg, Germany) and baseline heart rate using radial pulse measurements before workers began their work shift. Estimated core body temperatures were computed from baseline aural temperature, to which a standard adjustment for differences between core and aural temperatures were applied (Huggins et al., 2012), and continuous heart rate using the Buller algorithm. Physiological strain index (PSI), a measure of heat strain, was computed using equation 1.

Ambient weather conditions were obtained from AgWeatherNet weather stations, which log data every 15 minutes. We identified the closest station to each person on each participant date. Heat indices were calculated from temperature and humidity using Rothfusz's modification of Steadman's work (Rothfusz and Headquarters, 1990). Data were trimmed for each person to match their shift times. Summary metrics were calculated for the mean and maximum shift heat indices and air temperatures. Table 4 lists weather information and heat indices.

Table 4 Weather Data for Specific Aim 2: Heat Intervention (Summer 2019)

Month	Group	Mean temperature (°C) (SD)	Mean max temperature (°C) (SD)	Mean heat index (°C) (SD)	Mean max heat index (°C) (SD)
June	comparison	79.7 (5.3)	87.9 (5.7)	78.2 (5.2)	85.4 (5.4)
June	intervention	78.3 (4.8)	86.5 (6.0)	76.7 (4.9)	83.8 (5.4)
July	comparison	77.3 (7.9)	85.4 (8.1)	75.8 (7.2)	83.7 (7.1)
July	intervention	75.0 (3.9)	84.0 (6.8)	74.4 (4.2)	83.4 (7.0)
August	comparison	81.1 (7.3)	89.2 (7.6)	79.6 (7.1)	87.4 (7.6)
August	intervention	73.5 (4.6)	83.7 (6.4)	72.7 (4.7)	82.4 (6.0)

Covariates

We collected data on covariates that may serve as confounders or precision variables in our analysis. Workers filled out a baseline survey including information about demographic, health, work, and community factors that may be related to heat knowledge and heat-related illness. Age, gender, education, chronic health conditions, previous heat-related illness, comfort reading in English and Spanish, number of days worked in the past week, cooling opportunities at work, being allowed to take extra breaks at work, length of time to walk to the toilet at work, previous heat-related illness training, and ability to cool down at home or in the community were recorded.

Workplace size (small or large), hours, breaks, and information about which workers are part of the US H-2A guest workers program were noted by field research staff on heat strain assessment days. The H-2A program allows agricultural employees to hire workers from other countries on temporary work permits for agricultural jobs. In addition, workers completed a brief survey in English or Spanish on heat strain assessment days and answered questions on weekly questionnaires on work tasks, crops, and payment type (e.g. piece-rate or hourly). Research staff also observed workers' clothing.

Statistical analysis

For our inferential analysis, the primary hypothesis is that workers who receive the HEAT intervention will exhibit less heat strain compared to workers in the comparison group.

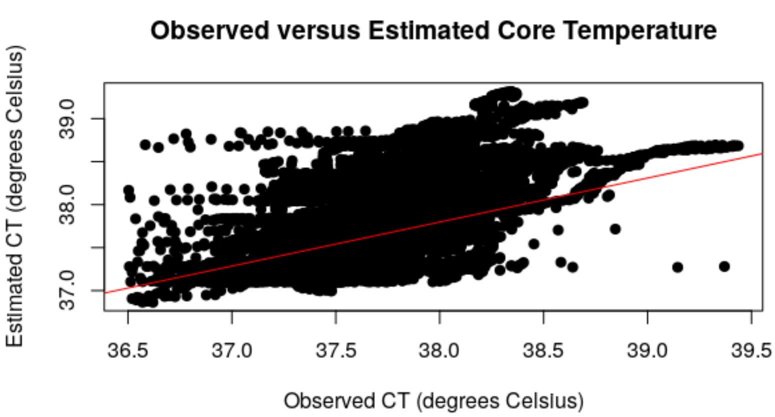
We assessed the association between work shift PSI and group status (intervention versus comparison, with group assigned using intent-to-treat) using linear mixed effects models and random effects for workers. The model included a term for max heat index and employer, as fixed effects. We also adjusted for the following potential confounders: age, gender, and average BMI. Estimates of the association between work shift max PSI and group status (intervention vs. comparison) were reported.

RESULTS

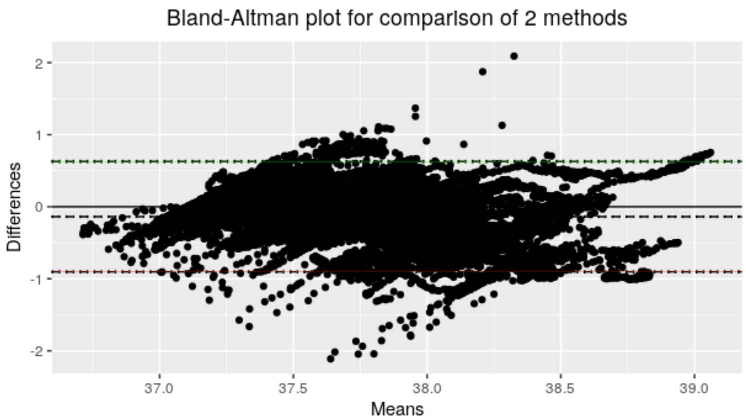
Specific Aim 1: Validation of the Buller Algorithm

Figure 2 shows the Buller algorithm accuracy using estimated and observed core temperature (CT) data with 37.1°C as baseline temperature for all participants through a scatter plot (Figure 2a), Bland-Altman plot (Figure 2b), and histogram of errors (Figure 2c). The overall bias is -0.14°C with LoA of ±0.76. The overall bias was negative, indicating that the observed values were, on average, larger than the estimated values.

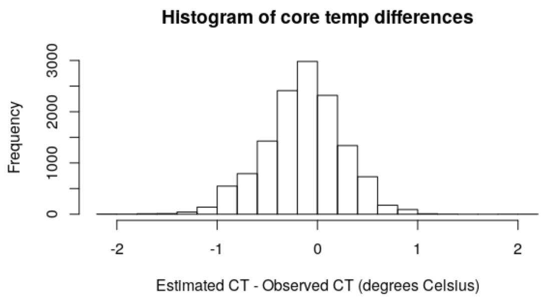
Figure 2. Buller Algorithm accuracy using estimated and observed core temperature (CT) data using 37.1°C as baseline temperature for all participants. (a) Scatter plot of observed versus estimated core temperature with the least squares regression line. (b) Bland-Altman plot showing the bias (center line) and LoA (top and bottom lines). (c) Histogram of error between observed and estimated temperatures.



(a)



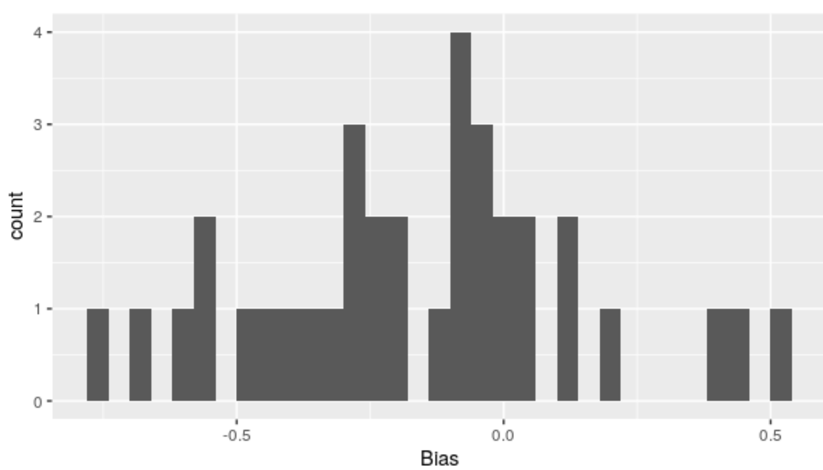
(b)



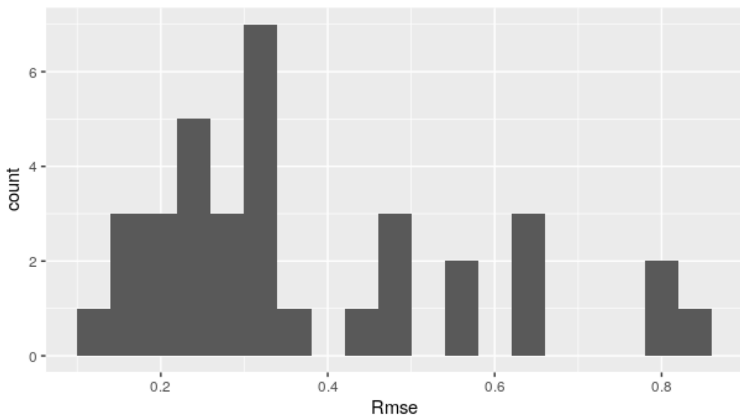
(c)

A bias, LoA, RMSE, and MAE were calculated for each individual and are shown in Table 5 (Appendix D). A histogram of the resulting values can be seen in Figure 3.

Figure 3. Histogram of core temperature estimation (a) bias and (b) RMSE calculated for each individual.



(a)



(b)

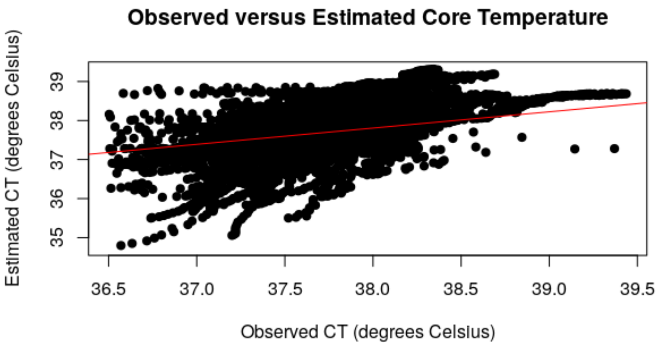
Table 6 shows the bias, LoA, RMSE, and MAE for all the participants using 37.1°C as the baseline temperature. Participants were broken down into subgroups: males, females, pear harvesters, and apple harvesters, and the bias, LoA, RMSE, and MAE were computed for each group. For males, bias was -0.16°C with LoA of ±0.73, RMSE 0.41, and MAE 0.31. For females, bias was -0.0047 with LoA of ±0.93, RMSE 0.48, and MAE 0.41. For pear harvesters, bias was -0.22 with LoA of ±0.72, RMSE 0.43, and MAE 0.32. For apple harvesters, bias was 0.12 with LoA of ±0.68, RMSE 0.37, and MAE 0.31.

Table 6. Bias (computed using the Bland-Altman method), limits of agreement (LoA), root mean squared error (RMSE), and mean absolute error (MAE) between observed and estimated CT using 37.1°C as the baseline temperature

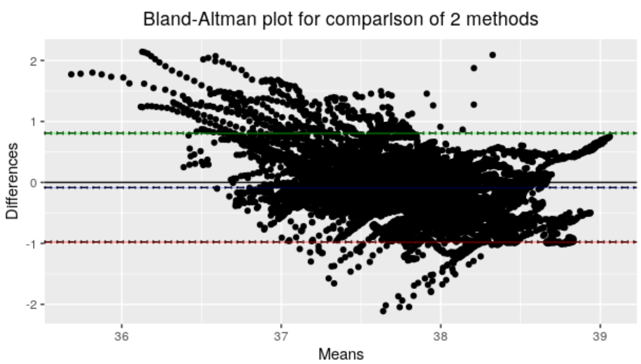
	Bias (°C)	**Lower limits of agreement**	**Upper limits of agreement**	**LoA**	**RMSE**	**MAE**
(N = 35)	-0.14	-0.90	0.63	±0.76	0.41	0.32
Males (n=31)	-0.16	-0.89	0.58	±0.73	0.41	0.31
Females (n=4)	-0.0047	-0.94	0.93	±0.93	0.48	0.41
Pear harvesters (August) (n=27)	-0.22	-0.94	0.50	±0.72	0.43	0.32
Apple harvesters (Sept.) (n=8)	0.12	-0.56	0.81	±0.68	0.37	0.31

Figure 4 shows the Buller algorithm accuracy using estimated and observed core temperature (CT) data with aural temperature +0.27°C as baseline temperature for all participants through a scatter plot (Figure 4a), Bland-Altman plot (Figure 4b), and histogram of errors (Figure 4c). The overall bias is -0.085°C with LoA of ±0.90.

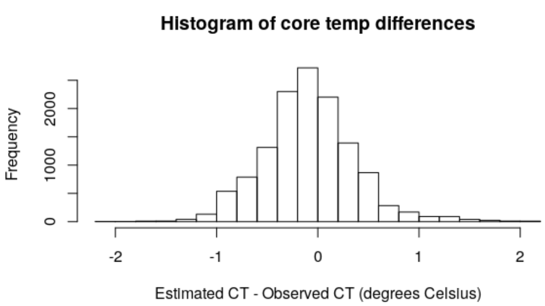
Figure 4. Buller Algorithm accuracy using estimated and observed CT data using aural temperature +0.27°C as baseline temperature for all participants. (a) Scatter plot of observed versus estimated core temperature with the least squares regression line. (b) Bland-Altman plot showing the bias (center line) and LoA (top and bottom lines). (c) Histogram of error between observed and estimated temperatures.



(a)



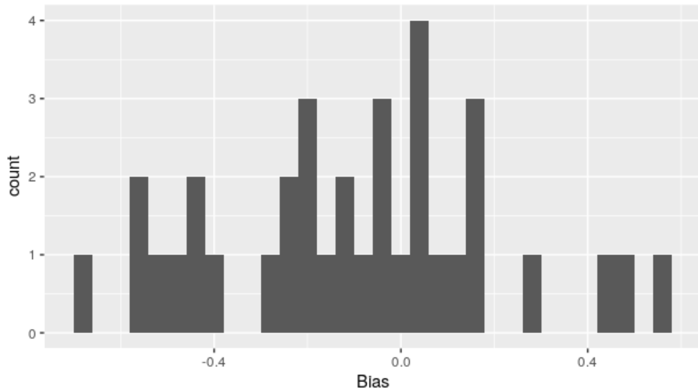
(b)



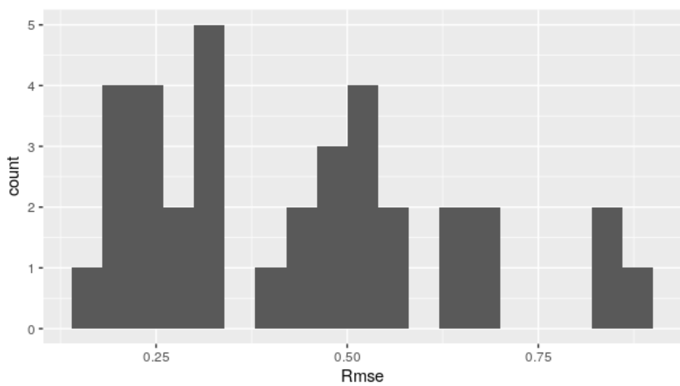
(c)

An overall bias and RMSE value were calculated for all the participants using aural temperature +0.27°C. Figure 5 depicts these results.

Figure 5. Histogram of core temperature estimation (a) bias and (b) RMSE calculated for each individual using aural temperature +0.27°C as the baseline temperature in the Buller algorithm.



(a)



(b)

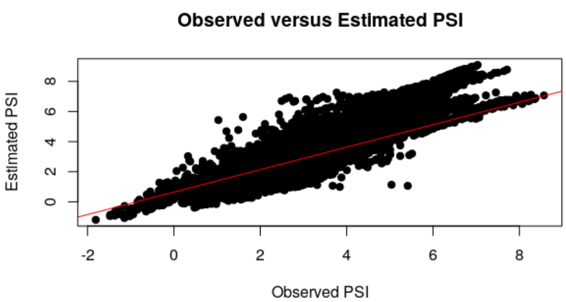
Table 7 shows the bias, LoA, RMSE, and MAE for all the participants using the aural temperature +0.27°C as the baseline temperature. Participants were broken down into subgroups: males, females, pear harvesters, and apple harvesters, and the bias, LoA, RMSE, and MAE were computed for each group. For males, the bias was -0.10°C with LoA of ±0.87, RMSE 0.46, and MAE 0.34. For females, bias was 0.024 with LoA of ±1.0, RMSE 0.52, MAE 0.43. For pear harvesters, bias was -0.16 with LoA of ±0.86, RMSE 0.47, and MAE 0.35. For apple harvesters, bias was 0.18 with LoA of ±0.78, RMSE 0.44, and MAE 0.35.

Table 7. Bias (computed using the Bland-Altman method), limits of agreement (LoA), root mean squared error (RMSE), and mean absolute error (MAE) between observed and estimated CT using aural temperature +0.27°C as the baseline temperature

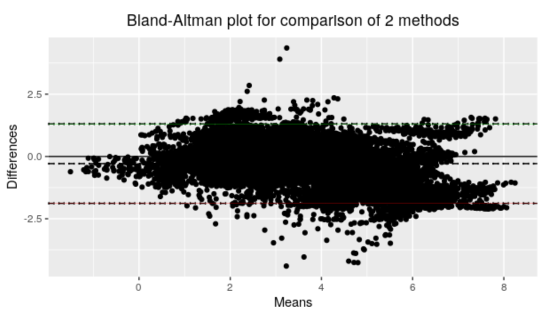
	Bias (°C)	Lower limits of agreement	Upper limits of agreement	LoA	RMSE	MAE
(N = 35)	-0.085	-0.98	0.81	±0.90	0.46	0.35
Males (n=31)	-0.10	-0.97	0.77	±0.87	0.46	0.34
Females (n=4)	0.024	-0.99	1.03	±1.0	0.52	0.43
Pear harvesters (August) (n=27)	-0.16	-1.03	0.70	±0.86	0.47	0.35
Apple harvesters (September) (n=8)	0.18	-0.60	0.96	±0.78	0.44	0.35

Figure 6 illustrates the accuracy for PSI, which was calculated using observed and estimated core temperatures. CT_0 was 37.1°C. The PSI had a bias and LoA of -0.29 ±1.59, with an RMSE of 0.86. Negative PSI values are seen when CT< CT_0 or HR < HR_0.

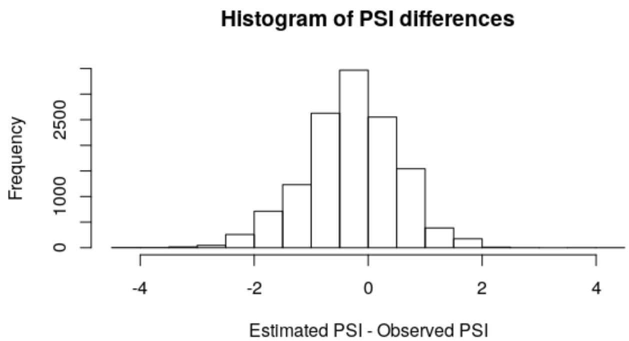
Figure 6. (a) Scatter plot of observed versus estimated PSI with the least squares regression line (CT_0 was 37.1°C). (b) Bland-Altman plot showing the bias (center line) and LoA (top and bottom lines). (c) Histogram of error between observed and estimated PSI. Histogram of model error for (d) bias and (e) RMSE.



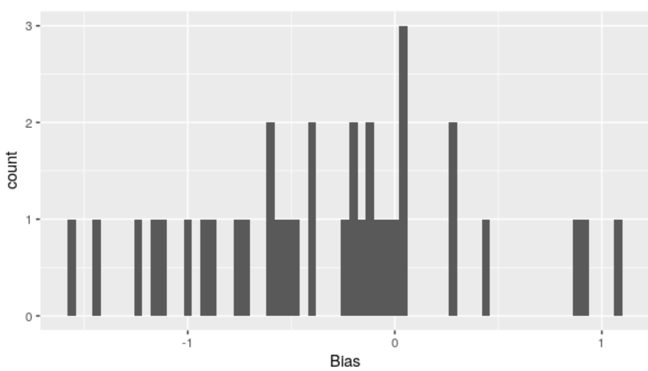
(a)



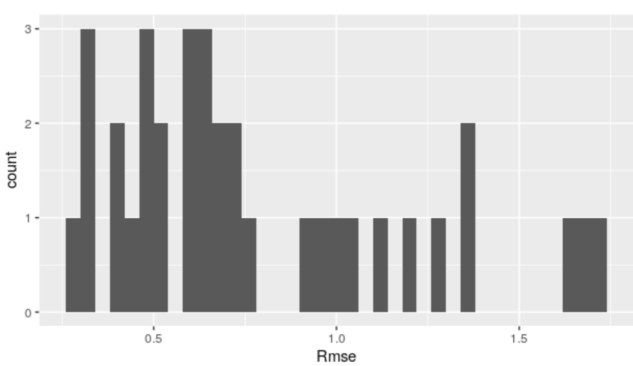
(b)



(c)



(d)



(e)

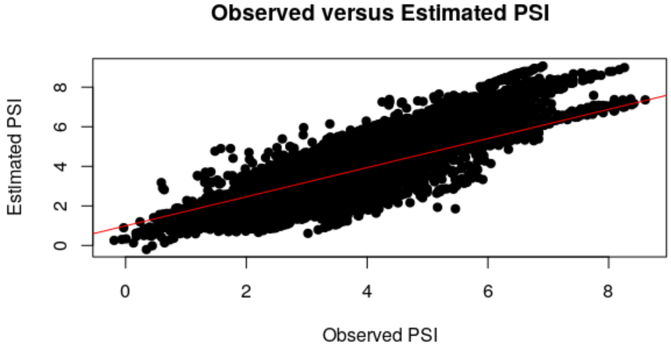
Table 8 shows the PSI bias, LoA, RMSE, and MAE for all the participants using 37.1°C as the baseline temperature. Participants were broken down into subgroups: males, females, pear harvesters, and apple harvesters, and the bias, LoA, RMSE, and MAE were computed for each group. For males, bias was -0.32°C with LoA of ±1.52, RMSE 0.84, and MAE 0.64. For females, bias was -0.0099 with LoA of ±1.94, RMSE 0.99, and MAE 0.85. For pear harvesters, bias was -0.45 with LoA of ±1.5, RMSE 0.89, and MAE 0.67. For apple harvesters, bias was 0.25 with LoA of ±1.42, RMSE 0.77, and MAE 0.64.

Table 8. Bias, limits of agreement (LoA), root mean squared error (RMSE), and mean absolute error (MAE) between observed and estimated PSI using 37.1°C as the baseline temperature

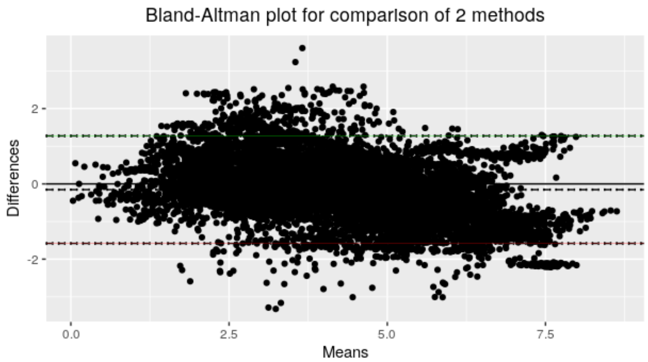
	Bias	**Lower limits of agreement**	**Upper limits of agreement**	**LoA**	**RMSE**	**MAE**
(N = 35)	-0.29	-1.88	1.31	±1.59	0.86	0.67
Males (n=31)	-0.32	-1.85	1.20	±1.52	0.84	0.64
Females (n=4)	-0.0099	-1.95	1.94	±1.94	0.99	0.85
Pear harvesters (August) (n=27)	-0.45	-1.95	1.05	±1.5	0.89	0.67
Apple harvesters (September) (n=8)	0.25	-1.17	1.68	±1.42	0.77	0.64

Figure 7 illustrates the values obtained for PSI which were calculated using observed and estimated core temperatures. CT_0 was aural temperature +0.27°C. The PSI has a bias and LoA of -0.15 ±1.42, with an RMSE of 0.74.

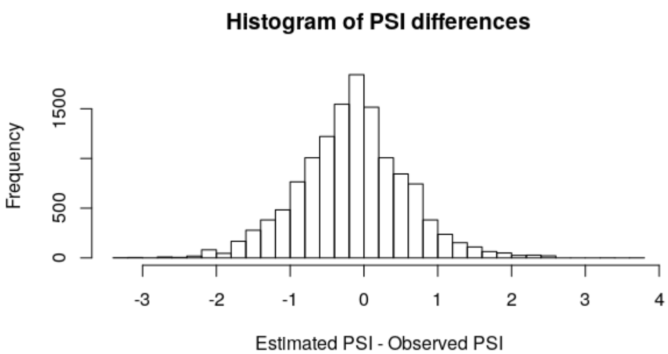
Figure 7. (a) Scatter plot of observed versus estimated PSI with the least squares regression line (CT_0 was aural temperature +0.27°C). (b) Bland-Altman plot showing the bias (center line) and LoA (top and bottom lines). (c) Histogram of error between observed and estimated PSI. Histogram of model error for (d) bias and (e) RMSE.



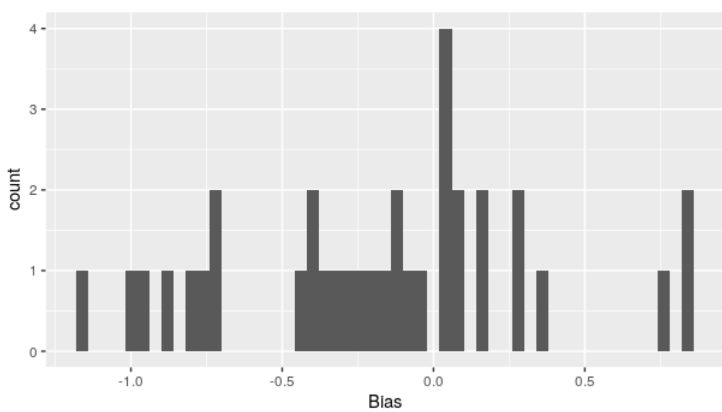
(a)


Bland-Altman plot for comparison of 2 methods
Differences
Means

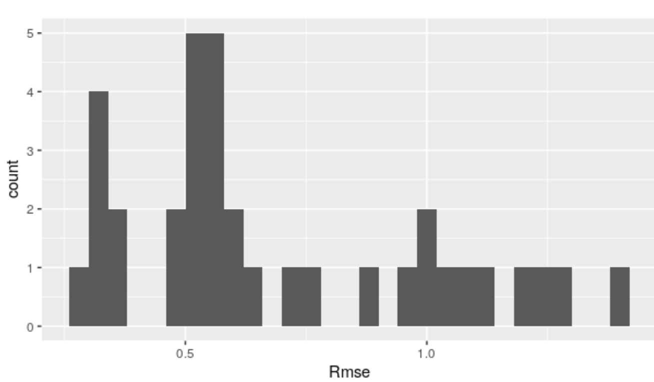
(b)


Histogram of PSI differences
Frequency
Estimated PSI - Observed PSI

(c)


count
Bias

(d)


count
Rmse

(e)

Table 9 shows the PSI bias, LoA, RMSE, and MAE for all the participants using the aural temperature +0.27°C as the baseline temperature. Participants were broken down into subgroups: males, females, pear harvesters, and apple harvesters, and the bias, LoA, RMSE, and MAE were computed for each group. For males, bias was -0.17°C with LoA of ±1.37, RMSE 0.72, and MAE 0.54. For females, bias was -0.050 with LoA of ±1.79, RMSE 0.91, MAE 0.77. For pear harvesters, bias was -0.28 with LoA of ±1.4, RMSE 0.77, and MAE 0.58. For apple harvesters, bias was 0.26 with LoA of ±1.19, RMSE 0.67, and MAE 0.54.

Table 9. Bias, limits of agreement (LoA), root mean squared error (RMSE), and mean absolute error (MAE) between observed and estimated PSI using aural temperature +0.27°C as the baseline temperature

	Bias	**Lower limits of agreement**	**Upper limits of agreement**	**LoA**	**RMSE**	**MAE**
(N = 35)	-0.15	-1.58	1.27	±1.42	0.74	0.57
Males (n=31)	-0.17	-1.54	1.20	±1.37	0.72	0.54
Females (n=4)	-0.050	-1.84	1.74	±1.79	0.91	0.77
Pear harvesters (August) (n=27)	-0.28	-1.68	1.4	±1.4	0.77	0.58
Apple harvesters (September) (n=8)	0.26	-0.93	1.19	±1.19	0.67	0.54

Specific Aim 2: Heat Intervention

Table 10 shows the CT outcomes by date for the comparison and intervention groups. The total mean (standard deviation [SD]) of mean shift CTs was 37.3°C (0.3) and 37.3°C (0.3) for the comparison and intervention groups, respectively. The total mean (SD) of max shift CTs was 37.7°C (0.3) and 37.7°C (0.3) for the comparison and intervention groups, respectively. The mean (SD) proportion of number of observations for CT above 38°C was 0.06 (0.13) and 0.05 (0.12) for the comparison and intervention groups, respectively.

Table 10 CT Outcomes by Date for Comparison and Intervention Groups

Date	Group	N	Mean CT (°C)	SD of Mean CT (°C)	MAX CT (°C)	SD of Max CT (°C)	Mean Proportion of Number of Observations for CT Above 38	SD of Mean Proportion of Number of Observations for CT Above 38
6/10/2019	control	6	37.4	0.2	37.9	0.3	0.05	0.09
6/10/2019	intervention	5	37.6	0.2	38.0	0.2	0.06	0.06
6/11/2019	control	7	37.3	0.3	37.8	0.4	0.04	0.11
6/11/2019	intervention	7	37.5	0.2	37.9	0.3	0.06	0.08
6/12/2019	control	7	37.4	0.2	37.9	0.2	0.01	0.03
6/12/2019	intervention	7	37.3	0.1	37.7	0.2	0.00	0.00
6/13/2019	control	4	37.5	0.2	38.2	0.5	0.16	0.11
6/13/2019	intervention	7	37.6	0.2	38.1	0.3	0.09	0.11
6/17/2019	control	6	37.1	0.4	37.5	0.4	0.03	0.07
6/17/2019	intervention	8	37.2	0.4	37.4	0.5	0.02	0.06
6/19/2019	control	6	37.1	0.1	37.4	0.2	0.00	0.00
6/19/2019	intervention	7	37.2	0.2	37.5	0.2	0.00	0.00
7/9/2019	control	4	37.1	0.2	37.5	0.3	0.00	0.00
7/9/2019	intervention	6	37.2	0.3	37.5	0.3	0.00	0.00
7/15/2019	control	6	37.4	0.3	37.8	0.3	0.07	0.17
7/15/2019	intervention	4	37.4	0.1	37.8	0.3	0.01	0.02
7/17/2019	control	6	37.3	0.1	37.6	0.1	0.00	0.00
7/17/2019	intervention	4	37.3	0.2	37.7	0.3	0.00	0.00
7/22/2019	control	7	37.2	0.4	37.5	0.4	0.01	0.03
7/22/2019	intervention	8	37.1	0.3	37.4	0.4	0.02	0.04
7/24/2019	control	6	37.1	0.2	37.3	0.3	0.00	0.00
7/24/2019	intervention	7	37.2	0.3	37.5	0.2	0.00	0.00
8/12/2019	control	6	37.3	0.2	37.7	0.3	0.03	0.08
8/12/2019	intervention	5	37.3	0.2	37.6	0.3	0.00	0.00
8/20/2019	control	9	37.3	0.3	37.6	0.4	0.04	0.11
8/20/2019	intervention	8	37.0	0.1	37.3	0.2	0.00	0.00
8/22/2019	control	4	37.2	0.4	37.5	0.5	0.03	0.06
8/22/2019	intervention	5	37.3	0.2	37.5	0.2	0.00	0.00
8/26/2019	control	3	37.6	0.1	38.5	0.3	0.33	0.15
8/26/2019	intervention	6	37.7	0.3	38.1	0.2	0.19	0.20
8/28/2019	control	8	37.7	0.2	38.4	0.2	0.30	0.19
8/28/2019	intervention	4	38.0	0.2	38.7	0.4	0.46	0.20
TOTAL	control	95	37.3	0.3	37.7	0.4	0.06	0.13
TOTAL	intervention	98	37.3	0.3	37.7	0.4	0.05	0.12

Table 11 shows the PSI outcomes by date for the comparison and intervention groups. The total max PSI was 4.6 (1.5) and 4.3 (1.53) for the comparison and intervention groups, respectively. The total mean (SD) PSI was 2.8 (1.0) and 2.5 (1.1) for the comparison and intervention groups, respectively.

Table 11 PSI Outcomes by Date for the Comparison and Intervention Groups

Date	Group	N	Mean PSI	SD of Mean PSI	Max PSI	SD of Max PSI
6/10/2019	comparison	6	3.4	0.3	5.6	0.8
6/10/2019	intervention	5	2.9	0.5	5.1	0.7
6/11/2019	comparison	7	2.9	0.8	5.1	1.5
6/11/2019	intervention	7	2.7	0.6	5.1	1.1
6/12/2019	comparison	7	3.5	0.5	5.6	0.7
6/12/2019	intervention	7	3.2	0.6	5.4	1.1
6/13/2019	comparison	4	3.0	1.0	6.0	2.0
6/13/2019	intervention	7	3.0	0.6	5.6	1.0
6/17/2019	comparison	6	1.9	0.8	3.6	0.9
6/17/2019	intervention	8	2.2	1.3	3.3	1.5
6/19/2019	comparison	6	1.6	0.5	3.1	0.6
6/19/2019	intervention	7	2.1	0.7	3.6	0.9
7/9/2019	comparison	4	3.3	0.2	4.9	0.6
7/9/2019	intervention	6	2.8	0.7	4.2	0.8
7/15/2019	comparison	6	3.2	0.7	5.1	1.0
7/15/2019	intervention	4	2.6	0.7	5.0	1.2
7/17/2019	comparison	6	2.5	0.6	4.0	0.4
7/17/2019	intervention	4	2.2	0.8	3.9	1.1
7/22/2019	comparison	7	1.8	1.2	3.4	1.4
7/22/2019	intervention	8	1.3	1.1	3.2	1.9
7/24/2019	comparison	6	1.8	0.7	2.9	0.9
7/24/2019	intervention	7	1.3	0.8	3.0	0.7
8/12/2019	comparison	6	2.8	0.7	4.7	0.8
8/12/2019	intervention	5	2.1	0.4	3.6	0.5
8/20/2019	comparison	9	2.6	0.9	3.9	1.2
8/20/2019	intervention	8	1.6	0.9	3.0	0.8
8/22/2019	comparison	4	2.2	1.2	3.6	1.5
8/22/2019	intervention	5	2.0	0.6	3.7	0.2
8/26/2019	comparison	3	3.1	0.4	6.5	0.9
8/26/2019	intervention	6	3.8	0.7	5.6	0.7
8/28/2019	comparison	8	4.4	0.6	6.6	0.8
8/28/2019	intervention	4	4.9	0.7	7.6	1.3
TOTAL	comparison	95	2.8	1.0	4.6	1.5
TOTAL	intervention	98	2.5	1.1	4.3	1.5

Table 12 shows the linear mixed effect model of group status (intervention vs. comparison) with max PSI as the main outcome. The unadjusted model had an effect estimate of -0.26. The model was adjusted for employer (i.e. farm company). This minimally-adjusted model had an effect estimate of -0.22. A moderately-adjusted model was adjusted for employer and max HI, and the effect estimate was -0.13. A fourth model adjusted for these potential confounders: employer, age, gender, average BMI, and max HI, and the adjusted effect estimate was -0.083.

Table 12 Effect Estimates and 95% Confidence Intervals from Linear Mixed Effect Model of Group Status (Intervention vs. Comparison)

Characteristic	Unadjusted effect estimate (95% confidence interval)	Minimally-adjusted model (95% confidence interval)`	Moderately-adjusted model (95% confidence interval)	Finally adjusted effect estimate (95% confidence interval)
Max PSI	-0.26 (-0.84, 0.31)	-0.22 (-0.57, 0.13)	-0.13 (-0.50, 0.25)	-0.083 (-0.46, 0.29)
Farm GG (ref Co-Ti)		1.09 (0.52, 1.66)	0.82 (0.21, 1.44)	0.56 (-0.17, 1.3)
Farm SM (ref Co-Ti)		-0.99 (-1.56, -0.42)	-1.41 (-2.06, -0.74)	-1.02 (-1.74, -0.25)
Age				-0.033 (-0.055, -0.011)
Male (ref female)				-0.083 (-0.64, 0.48)
Average BMI				0.040 (-0.000025, 0.080)
Max HI			0.041 (0.0083, 0.071)	0.046 (0.011, 0.074)

DISCUSSION

Specific Aim 1: Validation of the Buller Algorithm

The overall CT bias was -0.14°C when 37.1°C was used as the baseline temperature in the Buller algorithm, indicating that the error between measuring CT internally with a pill or estimating CT using heart rate via the Buller algorithm is small. The LoA were ±0.76. To determine an acceptable range for LoA, Buller examined the literature for esophageal and rectal temperatures. Buller shows the following comparisons for measurements of esophageal and rectal temperatures (Table 13, Buller et al., 2013). He reported that taking a weighted mean of all studies suggested that 95% of comparisons of rectal versus esophageal CTs fall within ±0.58°C. The varying values for CT shows the difficulty of producing close-fitting agreement in using different methods to measure CT. Buller also compared esophageal and pulmonary arterial blood temperature methods and found the LoA were ±0.59°C. Comparing rectal temperature and pulmonary arterial blood temperature methods resulted in LoA of ±0.78°C (Lefrant et al., 2003). The accuracy of the core temperature pill is ±0.1°C (CorTemp. HQ, Inc., 2021). This adds additional variability in that there is also uncertainty in the 'gold standard' that is not being captured in the comparison.

Table 13 Bias and LoA for Studies Comparing Rectal and Esophageal Measure of CT

Citation	Bias ± SD	LoA (1.96 * SD)	*N*
Kolka[a]	–0.21 ± 0.17	± 0.33	4
Lee[a]	–0.35 ± 0.20	± 0.40	7
Teunissen *et al* (2011)	0.01 ± 0.32	± 0.63	10
Brauer *et al* (1997)	–0.03 ± 0.42	± 0.82	60
Al-Mukhaizeem *et al* (2004)	0.05 ± 0.22[b]	± 0.43[b]	80
	Weighted Mean	± 0.58	161

[a] In Byrne and Lim (2007).
[b] Weighted mean of three periods in table 1, Al-Mukhaizeem *et al* (2004).

The overall LoA of ±0.76 indicate that 95% of all CT estimates fell within this range of the observed CT. This LoA is within the range found by Brauer et al. (1997) which was ±0.82°C and comparisons for rectal and pulmonary arterial blood temperature methods which were ±0.78°C.

For females, males, pear harvesters, and apple harvesters, all of the biases using 37.1°C as the baseline temperature (Table 6), are within ±0.25°C, which is the individual biological variation found by Consolazio et al. (1963). The LoA for males, pear harvesters, and apple harvesters are < ±0.76. Females did not fall within this range, as LoA was ±0.93°C. However, this is likely also influenced by the small sample size of females in this portion of the study (n=4).

The overall bias was -0.085°C when aural temperature +0.27°C was used as the baseline temperature in the Buller algorithm. The LoA was ±0.90. This wider range may indicate increased physiological and analytical imprecision inherent in taking aural temperatures. For females, males, pear harvesters, and apple harvesters, all of the biases were within ±0.25°C (Table 7). Apple harvesters were the only subgroup with a LoA within the range of ±0.78. The LoA for males, females, and pear harvesters did not fall within this range. We suspect this may be due to the variability associated with the physiological and analytical imprecision of aural temperatures.

The CT estimation worked very well except for a few individuals shown in Table 5. We were not able to identify a clear pattern for why some are more accurate than others. It did not appear that any one group (males, females, pear harvesters, or apple harvesters) had a much different bias than others. All the biases were within ±0.2°C. The LoA were all within ±0.68°C to ±0.87°C, except for the females who had a wider range of LoA, likely due to a small sample size.

PSI accuracy

The overall bias for PSI was -0.29 when 37.1°C was used as the baseline temperature (Table 8). The LoA were ±1.59. Showers reported a bias of -0.01 (also using 37.1°C as the baseline temperature) for PSI and LoA of ±1.2, which he reported was "comparable to the LoA resulting from the variability in computing PSI with two different ingestible capsule temperatures." (Showers et al., 2016)

The bias for pear harvesters was the furthest away from zero (-0.45) and the bias for females was the closest to zero (-0.0099) (Table 8). However, the LoA for females were the largest (±1.94). This may be due to the small sample size for females.

Biases were much lower for the aural temperature group (between -0.28 and 0.26) and LoA were lower for that group as well (between 1.19 and 1.4, with females being the outlier having LoA of 1.74 (Table 9).

The PSI risk is categorized into five different strain levels (Figure 1). Each level has a range of 2. A range > 2 for our results would be problematic because then the uncertainty of an individual falling in the wrong PSI level would be greater. In our study, the biases are well under 2. Most biases fell within ±0.3, with the exception of pear harvesters, having a bias of -0.45 (Table 8). The LoA, however, had a wider spread (~1.5).

This could potentially place a few individuals into a category they would not have otherwise fallen into. The risk being an individual put into a category lower than what they should be and, in practical applications, missing preventive treatments. The implications depend on whether values are being used for research versus practical application. This method may be better suited to groups rather than individuals.

Specific Aim 2: Heat Intervention

The total mean and max CT values were very similar for the comparison and intervention groups, but the mean proportion of number of observations for CT above 38°C was lower for the intervention group (Table 10). The mean PSI and max PSI were lower for the intervention group (Table 11).

In linear mixed effect model of group status (intervention vs. comparison) with max PSI as the main outcome, the unadjusted model had an effect estimate of -0.26 (Table 12). The negative value indicates the intervention group experienced a max PSI 0.26 lower than the comparison group. However, this result was not statistically significant as the confidence interval includes zero. We would expect the max PSI to be lower for the intervention group which the negative effect estimate indicates.

In the minimally-adjusted model, which was adjusted for employer, the effect estimate was -0.22. This was almost identical to the unadjusted model showing employer, by itself, was not a strong confounder. The variance of the random effects for the participants (not the residuals; between participant variability) was 1.136 for the unadjusted model. The variance of the random effects for the participants (not the residuals) in the minimally adjusted model was 0.1503. This indicates the between-person variability declined substantially when farm was taken into account.

The fully-adjusted model took into account these potential confounders: employer, age, gender, average BMI, and max HI. The adjusted effect estimate was -0.083. This effect estimate is different from the unadjusted model, indicating possible confounding.

The max heat indices for June, July, and August were highest for the SM farm, followed by the GG farm (the max HI for June SM and August GG were very similar), and then the small farms Co-Ti. The heat indices for Co-Ti were never above 80. The Co-Ti farms were located in a cooler place (higher in elevation towards the foothills). The SM farm was in the hottest location and had more heat monitoring days later in the summer when the temperature was hotter. The Max PSI was highest for the GG farms followed closely by the Co-Ti farms. The SM farms had the lowest PSIs. This is not what we would expect. We would expect the PSI to be highest at the highest heat indices. This may suggest that exertion plays a substantial role in addition to heat indices in predicting PSI values. The type of task workers were assigned may also influence PSI. Further research will need to be conducted to investigate task/exertion and to examine the possibility of effect modification by task/exertion and heat index.

Limitations

For Aim 1, our study participants were selected via convenience sampling methods which may have caused some selection bias. A large experimental study with numerous heat exposed participants in multiple regions would be an opportunity for future study to improve generalizability. Our study only included four female workers for Aim 1. Further work is needed to assess differences between males and females for the CT estimation in the Buller algorithm.

For Aim 2, limitations of the study include few data collection dates. The few assessment days for heat strain might not be as representative of the entire summer season. We aimed to sample during days when environmental temperatures were the greatest. These peak temperature days are ones of particular interest since CT and PSI are expected to be highest on those days. In addition, baseline heart rates were not available for some workers in the data set. We used a regression equation to predict resting heart rate for the 2015 workers from the first 5 minutes of measured heart rate data of the 2019 workers. Finally, intervention approaches should ultimately address overarching policies or other systemic changes, but policy changes were not directly addressed in our study. However, this analysis could support policy development by providing an evidence base for decisions.

Conclusion

Agricultural workers work under heat stress and are at risk for heat-related illness. The Buller algorithm, based only on heart rate and a baseline core temperature, was independently validated. When the Buller algorithm was applied to evaluate the effectiveness of the heat intervention study, intervention versus comparison group status was associated with a lower max PSI, but this was not statistically significant. Further analyses are needed to assess for potential effect modification, including by task type and exertion. The Buller algorithm may be a promising method for estimating CT and PSI in field conditions for research purposes.

Appendix A Demographic Data for Specific Aim 1

Table 1. Demographic Data and Survey Results for Specific Aim 1: Validation of the Buller Algorithm (Summer 2015)

	August pear harvest (n=27) mean (SD)		September apple harvest (n=8) mean (SD)		All (n=35) mean (SD)	
Demographics	**n**	**%**	**n**	**%**	**n**	**%**
Survey language (n=35)						
Spanish						
Age (n=35)						
18-24	5	18.5	0	0	5	14.3
25-44	16	59.3	3	37.5	19	54.3
45-64	6	22.2	5	62.5	11	31.4
Older than 64	0	0	0	0	0	0
Sex (n= 35)						
Male	26	96.3	5	62.5	31	88.6
Female	1	3.7	3	37.5	4	11.4
Hispanic or Latino (n=35)						
Yes	25	96.2	8	100	33	97.1
No	1	3.8	0	0	1	2.9
Years worked in agriculture						
Less than 1 year	3	11.1	0	0	3	8.6
1 to 2 years	2	7.4	0	0	2	5.7
3 to 5 years	4	14.8	0	0	4	11.4
6 to 9 years	2	7.4	0	0	2	5.7
10 or more years	16	59.3	8	100	24	68.6
When agriculture work commenced in 2015						
Before May	16	64	5	71.4	21	65.6
During the first half of May	3	12	1	14.3	4	12.5
During the last half of May	2	8	1	14.3	3	9.4
During the first half of June	1	4	0	0	1	3.1
During the last half of June	2	8	0	0	2	6.3
After June	1	4	0	0	1	3.1
I don't know						
Crops worked with in past week						
Apples	7	28	7	87.5	14	42.4
Pears	13	52	0	0	13	39.4
Cherries	3	12	0	0	3	9.1
Pears and cherries	0	0	0	0	0	0
Other tree fruit	0	0	0	0	0	0
Apples and other crops	0	0	1	12.5	1	3
Apples and pears	2	8	0	0	2	6.1
If worked with apples, main job task in the past week with apples						

Pruning						
Thinning blossoms	0	0	0	0	0	0
Thinning green fruit	4	44.4	0	0	4	23.5
Planting	0	0	0	0	0	0
Weeding	1	11.1	0	0	1	5.9
Picking or harvesting fruit	3	33.3	8	100	11	64.7
Mixing, loading, or applying pesticides	0	0	0	0	0	0
Sorting or packing fruit indoors	0	0	0	0	0	0
Sorting or packing fruit outdoors	0	0	0	0	0	0
Other jobs not listed here	1	11.1	0	0	1	5.9
How paid for work with apples						
By the hour	5	55.6	0	0	5	29.4
Piece rate	4	44.4	8	100	12	70.6
If worked with pears, main job task in the past week with pears						
Pruning	0	0	0	0	0	0
Thinning blossoms	0	0	0	0	0	0
Thinning green fruit	1	6.7	0	0	1	6.7
Planting	0	0	0	0	0	0
Weeding	0	0	0	0	0	0
Picking or harvesting fruit	14	93.3	0	0	14	93.3
Mixing, loading, or applying pesticides	0	0	0	0	0	0
Sorting or packing fruit indoors	0	0	0	0	0	0
Sorting or packing fruit outdoors	0	0	0	0	0	0
Other jobs not listed here	0	0	0	0	0	0
How paid for work with pears						
By the hour	0	0	0	0	0	0
Piece rate	14	100	0	0	14	100
How many days worked in the past week						
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	4	16	0	0	4	12.1
4	5	20	1	12.5	6	18.1
5	4	16	0	0	4	12.1
6	6	24	0	0	6	18.1
7	6	24	7	87.5	13	39.4
I did not work this past week						
In the past week, time of day usually started working						
Before 5 am	3	12	0	0	3	9.1
Between 5 am and 7 am	22	88	8	100	30	90.9
Between 7 am and 9 am	0	0	0	0	0	0
Between 9 am and 10 am	0	0	0	0	0	0
10 am or after	0	0	0	0	0	0
In the past week, time of day usually stopped working						
Before 10 am	0	0	0	0	0	0
Between 10 am and 12 pm	2	8	0	0	2	6.1
Between 12 pm and 1 pm	11	44	0	0	11	33.3

Between 1 pm and 3 pm	10	40	7	87.5	17	51.5
Between 3pm and 5 pm	2	8	1	12.5	3	9.1
5 pm or after	0	0	0	0	0	0
In the past week, length of morning break						
5 minutes	0	0	0	0	0	0
10 minutes	9	33.3	2	25	11	31.4
15 minutes	13	48.1	0	0	13	37.1
30 minutes	1	3.7	2	25	3	8.6
No morning break	4	14.8	4	50	8	22.9
In the past week, length of lunch break						
5 minutes	0	0	0	0	0	0
10 minutes	0	0	0	0	0	0
15 minutes	12	46.2	1	12.5	13	38.2
30 minutes	10	38.5	7	87.5	17	50
45 minutes	1	3.8	0	0	1	2.9
No lunch break	1	3.8	0	0	1	2.9
Other amount of time	2	7.7	0	0	2	5.9
In the past week, afternoon breaks taken						
Yes	11	40.7	1	12.5	12	34.3
No	16	59.3	7	87.5	23	65.7
In the past week, length of afternoon break						
5 minutes	2	50	0	0	2	40
10 minutes	2	50	1	100	3	60
15 minutes	0	0	0	0	0	0
30 minutes	0	0	0	0	0	0
Other amount of time	0	0	0	0	0	0
Extra breaks allowed						
Yes	24	96	7	87.5	31	93.9
No	1	4	1	12.5	2	6.1
Work hours gradually increased at the start of the season						
Yes	7	26.9	2	25	9	26.5
No	19	73.1	6	75	25	73.5
Beverages consumed at work						
Water	25	92.6	8	100	33	94.3
Sports drinks like Gatorade or Cytomax	10	37.0	1	12.5	11	31.4
Energy drinks like Red Bull, Monster, or 5-hour Energy	5	18.5	3	37.5	8	22.9
Fruit juice	6	22.2	4	50.0	10	28.6
Iced coffee or iced tea	2	7.4	1	12.5	3	8.6
Hot coffee or hot tea	4	14.8	3	37.5	7	20.0
Soda	15	55.6	7	87.5	22	62.9
Other drinks not listed here	1	3.7	1	12.5	2	5.7
Consume water as much as wanted (past week)						
Yes	26	96.3	7	87.5	33	94.3
No	1	3.7	1	12.5	2	5.7
How long it takes to walk to where there is drinking water						
Less than one minute	9	36	2	25	11	33.3

Between one to three minutes	13	52	5	62.5	18	54.5
Between three to five minutes	2	8	1	12.5	3	9.1
Between five to ten minutes	1	4	0	0	1	3
More than ten minutes	0	0	0	0	0	0
There is no drinking water	0	0	0	0	0	0
How long it takes to walk to a toilet						
Less than one minute	2	7.7	0	0	2	5.9
Between one to three minutes	7	26.9	0	0	7	20.6
Between three to five minutes	14	53.8	5	62.5	19	55.9
Between five to ten minutes	3	11.5	2	25	5	14.7
More than ten minutes	0	0	1	12.5	1	2.9
There is no toilet					0	0
Available resources at work to help workers cool down						
Shade structure	2	7.4	2	25	4	11.4
Trees	24	88.9	8	100	32	91.4
Fans	0	0	1	12.5	1	2.90
Rest stations	6	22.2	0	0	6	17.1
Building with air conditioning	0	0	0	0	0	0
Other cooling methods not listed here	0	0	0	0	0	0
No cooling methods available at work	0	0	0	0	0	0
Removed layers or unbuttoned or unzipped clothing in heat (past week)						
Yes	8	29.6	3	37.5	11	31.4
No	19	70.4	5	62.5	24	68.6
Available amenities at home						
Windows that can open	13	48.1	7	87.5	20	57.1
Air conditioning that works	22	81.5	7	87.5	29	82.9
Electric fan	14	51.9	3	37.5	17	48.6
None of these	0	0	0	0	0	0
Went somewhere other than home to cool down during the day						
Yes	13	48.1	3	37.5	16	45.7
No	14	51.9	5	62.5	19	54.3
Personal assessment of health						
Excellent	6	23.1	2	28.6	8	24.2
Very good	5	19.2	0	0	5	15.2
Good	8	30.8	3	42.9	11	33.3
Fair	7	26.9	2	28.6	9	27.3
Poor	0	0	0	0	0	0
Quality of sleep (past week)						
Very good	12	44.4	5	62.5	17	48.6
Fairly good	12	44.4	1	12.5	13	37.1
Fairly bad	3	11.1	2	25	5	14.3
Very bad	0	0	0	0	0	0
Informed by health provider of following condition						
Diabetes	1	3.7	1	12.5	2	5.7
High blood pressure	2	7.4	1	12.5	3	8.6
Heart disease	0	0	1	12.5	1	2.9

Lung disease, including asthma	0	0	0	0	0	0
Overweight or obese	2	7.4	1	12.5	3	8.6
Heat-related illness	0	0	0	0	0	0
Kidney disease	0	0	0	0	0	0
Liver disease	0	0	1	12.5	1	2.9
High cholesterol	2	7.4	2	25.0	4	11.4
Conditions affecting balance, including stroke and problems with the inner ear	0	0	0	0	0	0
Sleep problems, including obstructive sleep apnea	2	7.4	0	0	2	5.7
Cancer	0	0	0	0	0	0
None of the above	14	51.9	5	62.5	19	54.3
I don't know	6	22.2	6	75	6	17.1
Medications taken (past week)						
High blood pressure	2	7.40	0	0.00	2	5.70
Mental health conditions, including depression	0	0	0	0	0	0
Diet pills	0	0	0	0	0	0
Parkinson's disease	0	0	0	0	0	0
Heart disease	0	0	0	0	0	0
Constipation	0	0	0	0	0	0
Irritable bowel or bladder	0	0	0	0	0	0
Nose congestion, cough, or allergies	0	0	0	0	0	0
Seizures	0	0	0	0	0	0
Thyroid condition	0	0	0	0	0	0
Nausea	0	0	0	0	0	0
Pain, fever, or inflammation medication	6	22.20	3	37.5	9	25.70
High cholesterol	0	0	0	0	0	0
None of the above	17	63.00	5	62.50	22	62.90
I don't know	2	7.40	0	0	2	5.70
Immediate family members diagnosed with kidney disease						
Yes	3	11.1	0	0	3	8.6
No	24	88.9	8	100	32	91.4
Have other paid jobs that require physical work (past week)						
Yes	3	11.1	2	25	5	14.3
No	24	88.9	6	75	30	85.7
Pesticides sprayed in working areas (past week)						
Yes	3	14.3	0	0	3	11.5
No	18	85.7	5	100	23	88.5
Exposure to pesticide drift or residues (past week)						
Yes	4	16	0	0	4	12.1
No	21	84	8	100	29	87.9
Pesticides used at home (past week)						
Yes	8	29.6	0	0	8	22.9
No	19	70.4	8	100	27	77.1
Smoked at least 100 cigarettes in entire life						
Yes	13	52	4	50	17	51.5
No	12	48	4	50	16	48.5

Smoking habits						
Every day	2	7.4	1	12.5	3	8.6
Some days	9	59.3	1	12.5	10	28.6
Not at all	16	33.3	6	75	22	62.9
Smoking with cigars or pipes						
Every day	0	0	0	0	0	0
Some days	1	3.7	0	0	1	2.9
Not at all	26	96.3	8	100	34	97.1
Chew tobacco						
Every day	0	0	0	0	0	0
Some days	0	0	0	0	0	0
Not at all	27	100	8	100	35	100
At least one drink of any alcoholic beverage (past week)						
1 day	6	22.2	1	12.5	7	20
2 days	3	11.1	2	25	5	14.3
3 days	2	7.4	1	12.5	3	8.6
4 days	1	3.7	0	0	1	2.9
5 days	1	3.7	0	0	1	2.9
6 days	1	3.7	0	0	1	2.9
7 days	2	7.4	0	0	2	5.7
Did not drink in past week	11	40.7	4	50	15	42.9
Number of drinks consumed on days when alcohol was consumed						
1 or 2	9	56.3	3	75	12	60
3 or 4	1	6.3	1	25	2	10
5 or 6	2	12.5	0	0	2	10
More than 6	4	25	0	0	4	20
Concern about health being affected by working in hot conditions						
Not at all concerned	7	25.9	1	12.5	8	22.9
A little big concerned	15	55.6	3	37.5	18	51.4
Very concerned	4	14.8	4	50	8	22.9
No opinion	1	3.7	0	0	1	2.9
Experienced any health symptoms or illnesses thought to be related to work						
Yes	2	7.4	0	0	2	5.7
No	25	92.6	8	100	33	94.3
Fallen at work						
Yes	15	55.6	2	25	17	48.6
No	12	44.4	6	75	18	51.4
Heat caused dizziness or light-headedness						
Yes	1	6.7	0	0	1	5.9
No	14	93.3	2	100	16	94.1
Symptoms or illnesses experienced on a hot day at work (past week)						
Skin rash or skin bumps	0	0	0	0	0	0
Painful muscle cramps or spasms	4	14.8	0	0	4	11.4
Dizziness or light-headedness	1	2.9	0	0	1	2.9
Fainting	0	0	0	0	0	0
Headache	2	7.4	1	12.5	3	8.6

Heavy sweating	14	51.9	5	62.5	19	54.3
Extreme weakness and fatigue	1	2.9	0	0	1	2.9
Nausea or vomiting	0	0	0	0	0	0
Confusion	0	0	0	0	0	0
Other symptoms or illnesses	0	0	0	0	0	0
I did not experience any of these symptoms or illnesses	9	33.3	3	37.5	12	34.3
Received training about working outdoors in the heat or health effects of working in the heat (past year)						
Yes	10	40	2	25	12	36.4
No	15	60	6	75	21	63.6
Ability to read in Spanish						
Very well	17	63	4	50	21	60
Fairly well	9	33.3	2	25	11	31.4
Not very well	0	0	2	25	2	5.7
Not at all	1	3.7	0	0	1	2.9
Ability to read in English						
Very well	3	11.1	0	0	3	8.6
Fairly well	2	7.4	1	12.5	3	8.6
Not very well	5	18.5	0	0	5	14.3
Not at all	17	63	7	87.5	24	68.6
Level of education attained						
Part of primary school	5	18.5	1	12.5	6	17.1
Completed primary school	6	22.2	5	62.5	11	31.4
Part of middle school	4	14.8	1	12.5	5	14.3
Completed middle school	7	25.9	0	0	7	20
Part of high school	0	0	0	0	0	0
Completed high school	4	14.8	1	12.5	5	14.3
Part of college or university	1	3.7	0	0	1	2.9
Completed college or university	0	0	0	0	0	0
I did not go to school	0	0	0	0	0	0
Years lived in the U.S.						
Less than 1 year	2	7.4	0	0	2	5.7
1-2 years	2	7.4	0	0	2	5.7
3-4 years	3	11.1	0	0	3	8.6
5-6 years	0	0	0	0	0	0
8-10 years	5	18.5	0	0	5	14.3
More than 10 years	15	55.6	8	100	23	65.7
Reside in the U.S. all year						
Yes	24	88.9	8	100	32	91.4
No	3	11.1	0	0	3	8.6
Origin of birth						
U.S.	1	3.7	0	0	1	2.9
Mexico	25	92.6	8	100	33	94.3
Central America	1	3.7	0	0	1	2.9
South America	0	0	0	0	0	0
Other	0	0	0	0	0	0

*missing: years worked in agriculture (1), when agricultural work commenced in 2015 (3), crops worked with in past week (2) main job task in the past week with apples (18), how paid for work with apples (18), main job task in the past week with pears (20), how paid for work with pears (21), how many days worked in the past week (2), time of day usually started working (2), time of day usually stopped working (2), length of lunch break (1), length of afternoon break (30), extra break allowed (2), work hours gradually increased (1) how long to walk to drinking water (2), how long to walk to a toilet (1), personal assessment of health (2), pesticides sprayed in working areas (9), exposure to pesticide drift or residues (2), smoked at least 100 cigarettes in entire life (2) number of drinks alcoholic drinks consumed (15), heat caused dizziness or light-headedness (18), received training about working outdoors in the heat (2)

Appendix B Demographic Data for Specific Aim 2

Table 2. Demographic Data and Survey Results for Specific Aim 2: Heat Intervention (Summer 2019)

	All (n=75)		0 = Control (n=38)		1 = Intervention (n=37)	
Demographics	**n**	**%**	**n**	**%**	**n**	**%**
Survey language						
Spanish	75	100%	38	100	37	100%
Age						
18-24	10	13.3	5	13.2	5	13.5
25-44	30	40	14	36.8	16	43.2
45-64	28	37.3	15	39.5	13	35.1
Older than 64	7	9.3	4	10.5	3	8.1
Sex						
Male	48	64	21	55.3	27	73
Female	27	36	17	44.7	10	27
Level of education attained						
Part of primary school	20	27	11	28.9	9	25
Completed primary school	15	20.3	7	18.4	8	22.2
Part of middle school	1	1.4	1	2.6	0	0
Completed middle school	8	10.8	4	10.5	4	11.1
Part of high school	9	12.2	4	10.5	5	13.9
Completed high school	13	17.6	5	13.2	8	22.2
Part of college or university	3	4.1	3	7.9	0	0
Completed college or university	2	2.7	1	2.6	1	2.8
I did not go to school	3	4.1	2	5.3	1	2.8
Informed by health provider of following condition(s)						
Diabetes	5	7.7	3	8.8	2	6.5
High blood pressure	16	24.6	9	26.5	7	22.6
Heart disease	2	3.1	2	5.9	0	0
Lung disease, including asthma	3	4.6	3	8.8	0	0
Overweight or obese	6	9.2	2	5.9	4	12.9
Heat-related illness	1	1.5	1	2.9	0	0
Kidney disease	1	1.5	0	0	1	3.2
Liver disease	2	3.1	1	2.9	1	3.2
High cholesterol	7	10.8	4	11.8	3	9.7
Conditions affecting balance	1	1.5	0	0	1	3.2
Sleep difficulty	2	3.1	0	0	2	6.5
Cancer	0	0	0	0	0	0
None of the above	38	58.5	19	55.9	19	61.3
Ability to read in English						
Very well	4	6	3	9.1	1	2.9

Fairly well	6	9	4	12.1	2	5.9
Not very well	15	22.4	6	18.2	9	26.5
Not at all	42	62.7	20	60.6	22	64.7
Ability to read in Spanish						
Very well	43	57.3	22	57.9	21	56.8
Fairly well	24	32	12	31.6	12	32.4
Not very well	5	6.7	3	7.9	2	5.4
Not at all	3	4	1	2.6	2	5.4
How long it takes to walk to a toilet						
Less than one minute	14	19.2	9	23.7	5	14.3
Between one to three minutes	39	53.4	22	57.9	17	48.6
Between three to five minutes	15	20.5	4	10.5	11	31.4
Between five to ten minutes	4	5.5	2	5.3	2	5.7
More than ten minutes	0	0	0	0	0	0
There is no toilet	1	1.4	1	2.6	0	0
Received training about working outdoors in the heat or health effects of working in the heat (past year)						
Yes	54	73	24	63.2	30	83.3
No	20	27	14	36.8	6	16.7
I don't know	1					
Available amenities at home						
Windows that can open	55	73.3	29	76.3	26	70.3
Air conditioning that works	56	74.7	28	73.7	28	75.7
Electric fan	17	22.7	10	26.3	7	18.9
None of these	1	1.3	0	0	1	2.7
Strategies used to keep cool on hot days						
Take cool showers or baths	35	46.7	17	44.7	18	48.6
Use a fan	17	22.7	11	28.9	6	16.2
Use air conditioning	47	62.7	26	68.4	21	56.8
Avoid cooking inside	3	4	2	5.3	1	2.7
Close curtains/blinds when hot	9	12	5	13.2	4	10.8
Open windows when cool	27	36	11	28.9	16	43.2
Other	0	0	0	0	0	0
Went somewhere other than home to cool down during the day						
Yes	27	36	13	34.2	14	37.8
No	48	64	25	65.8	23	62.2
Workplace size						
Small	15	20	8	21.1	7	18.9
Large	60	80	30	78.9	30	81.1
H-2A worker						
Yes	28	37.3	14	36.8	14	37.8
No	47	62.7	24	63.2	23	62.2

*missing: level of education attained (1), informed by health provider of medical conditions (10), ability to read in English (8), how long it takes to walk to a toilet(2)

Appendix C HEAT Training

Description, design, & development of HEAT intervention

Advisory groups

Development of the HEAT intervention was guided by two advisory groups: 1) a technical advisory group; and 2) an expert working group (EWG). The technical advisory group included agricultural industry, government, and community representatives. The EWG included farmworkers and managers. The EWG model has been used successfully in agricultural health and safety and is based on the fundamental concept that farmers and farmworkers are innovators and experts in agriculture. The advisory groups provided feedback that was iteratively incorporated into the HEAT intervention. The final HEAT intervention consisted of: 1) worker HEAT training and; 2) a supervisor HEAT awareness application addressing risk factors for adverse heat health effects at multiple levels.

HEAT training

Heat training was developed using a relational and engaged approach. Relational approaches enhance inclusion by encouraging sharing of information and perspectives and have been shown to be associated with higher job satisfaction, which is associated with improved occupational health outcomes. Engaged approaches involve participants' active participation, and more active participation in health and safety training has been shown to be more effective. Though HEAT training will be delivered to agricultural workers by research staff in this study, HEAT training was designed to allow delivery by supervisors and other educators in the future ('train-the-trainer' approach).

HEAT training uses poster visual displays for ease of use in field, classroom, and other settings. Relational and engaged approaches are implemented through group discussion to learn more about participants' perspectives and to draw out knowledge and by reinforcement of key messages through activities. Training content includes factors at several SEM levels and covers the following topics: types of heat-related illness and treatments, risk factors for heat-related illness, clothing for work in hot weather, staying hydrated at work, personal protective equipment and heat, and keeping cool in the home and community. In addition, previous qualitative work to identify barriers to heat-related illness prevention in Latinx agricultural workers suggests that heat prevention training that does not address certain beliefs, such as beliefs some treatments for heat-related illness may harm health, may not be effective. These findings, as well as information about the increased risk of traumatic injury with increasing heat exposure, are integrated into the HEAT training. The training also complies with the Washington State Outdoor Heat Rule for Agriculture training requirements. In addition to feedback from advisory groups, the HEAT training was optimized based on feedback from focus groups and beta testing with promotores (community health workers) and agricultural workers, and from the University of Washington Center for Teaching and Learning.

HEAT awareness application

The HEAT awareness application was developed in collaboration with Washington State University's AgWeatherNet Program to notify supervisors signed up for the service about hot weather conditions that might increase the risk for adverse health effects for workers. AgWeatherNet maintains a network of 184 professional weather stations located mostly in the irrigated and agriculturally productive regions of eastern Washington, and supports web and mobile (e.g. IOS and Android) platforms with weather-related crop decision support tools. The HEAT awareness application is designed to ultimately allow AgWeatherNet subscribers to select weather stations of interest (e.g. closest to them) and view current heat indices as well as maximum daily heat indices forecasted over the following week. This information is coupled, using a color-coded risk-level approach, with information about workers' risk for adverse heat health effects and messages relevant to the agricultural industry for how to prevent adverse heat health effects, such as scheduling work during cooler parts of the day. During the study period, the HEAT awareness application will be available in English and Spanish to HEAT study intervention group supervisors.

Heat indices were calculated from temperature and humidity using Rothfusz's modification of Steadman's work, and forecasted heat indices were based on forecasted maximum daily air temperature and minimum daily humidity, since temperature and humidity are inversely related. American Conference of Governmental Industrial Hygienists (ACGIH) Heat Stress Threshold Limit Values guidelines, assuming workers wear regular work clothes without extra layers and are performing moderate physical work, and guidance from the US Occupational Safety and Health Administration were considered in developing risk levels and messages. Correspondence between ACGIH wet-bulb globe temperature (WBGT)-based guidance and heat indices was determined using published methods. Notifications are designed to be sent out to application users one and six days before a forecasted heat index of 91°F or higher. The application was optimized based on feedback from the project advisory groups.

Appendix D Individual BIASES, RMSES, and MAE values

Table 5. CT Bias, LoA, RMSE, and MAE calculated for each individual using 37.1 degrees Celsius as the baseline temperature

PARTICIPANT	Bias 37.1	Lower limits	Upper limits	LoA	RMSE	MAE
2	-0.70	-1.48	0.081	0.78	0.80	0.76
3	-0.75	-1.45	-0.046	0.70	0.83	0.75
5	0.010	-0.28	0.30	0.29	0.15	0.12
6	-0.34	-0.58	-0.095	0.24	0.36	0.34
7	0.13	-0.14	0.40	0.27	0.19	0.15
8	-0.28	-0.59	0.025	0.31	0.32	0.29
9	-0.48	-1.0	0.044	0.52	0.54	0.50
10	-0.36	-0.88	0.16	0.52	0.44	0.38
11	-0.067	-0.33	0.19	0.26	0.15	0.11
12	-0.20	-0.44	0.043	0.24	0.23	0.20
13	-0.047	-0.43	0.34	0.38	0.20	0.17
14	-0.026	-0.48	0.43	0.45	0.23	0.15
16	-0.12	-0.44	0.19	0.31	0.20	0.15
18	-0.067	-0.50	0.37	0.43	0.23	0.18
19	-0.24	-0.56	0.074	0.31	0.29	0.25
20	-0.60	-1.59	0.38	0.98	0.78	0.70
21	-0.43	-1.37	0.51	0.94	0.65	0.59
23	0.43	0.061	0.81	0.37	0.47	0.43
25	-0.27	-0.66	0.12	0.39	0.34	0.30
26	0.025	-0.45	0.50	0.48	0.24	0.18
27	-0.054	-0.65	0.54	0.59	0.31	0.25
28	-0.096	-0.35	0.15	0.25	0.16	0.10
29	-0.091	-0.73	0.55	0.64	0.34	0.30
31	-0.54	-1.25	0.16	0.70	0.65	0.56
32	-0.0060	-0.27	0.26	0.26	0.13	0.093
35	-0.56	-1.08	-0.041	0.52	0.62	0.59
36	-0.42	-0.95	0.11	0.53	0.50	0.43
39	0.42	0.022	0.81	0.39	0.46	0.42
40	0.20	-0.26	0.66	0.46	0.31	0.27
41	0.51	0.00023	1.02	0.51	0.57	0.51
42	0.020	-0.53	0.57	0.55	0.28	0.22
43	-0.19	-0.61	0.24	0.42	0.29	0.24
44	0.13	-0.26	0.53	0.39	0.24	0.20
45	-0.28	-0.51	-0.04	0.23	0.30	0.29
47	-0.23	-0.71	0.24	0.47	0.34	0.28

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