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The multi-level heat education and awareness tools [HEAT] intervention study for farmworkers: Rationale and methods

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ABSTRACT

Background: The burden of adverse health effects from heat exposure is substantial, and outdoor workers who perform heavy physical work are at high risk. Though heat prevention interventions have been developed, studies have not yet systematically evaluated the effectiveness of approaches that address risk factors at multiple levels.

Objective: We sought to test the effectiveness of a multi-level heat prevention approach (heat education and awareness tools [HEAT]), which includes participatory training for outdoor agricultural workers that addresses individual and community factors and a heat awareness mobile application for agricultural supervisors that supports decisions about workplace heat prevention, in the Northwest United States.

Design: We designed the HEAT study as a parallel, comparison, randomized group intervention study that recruited workers and supervisors from agricultural workplaces. In intervention arm crews, workers received HEAT training, and supervisors received the HEAT awareness application. In comparison arm crews, workers were offered non-HEAT training. Primary outcomes were worker physiological heat strain and heat-related illness (HRI) symptoms. In both worker groups, we assessed HRI symptoms approximately weekly, and heat strain physiological monitoring was conducted at worksites approximately monthly, from June through August.

Discussion: To our knowledge, this is the first study to evaluate the effectiveness of a multi-level heat prevention intervention on physiological heat strain and HRI symptoms for outdoor agricultural workers.

Trial registration: ClinicalTrials.gov Registration Number: NCT04234802;

1. Introduction

Agricultural workers who labor outdoors in hot conditions are at high risk for adverse health outcomes caused by heat stress. In the United States (US), between 2000 and 2010, 359 occupational heat-related deaths were recorded in the Census of Fatal Occupational Injuries (mean fatality rate 0.22 per 1 million workers), and the Agriculture, Forestry, Fishing, and Hunting sector had thirty-five times the rate of occupational heat-related fatalities compared to all other industries [1]. An analysis of Washington State workers' compensation data from 2006 to 2017 indicated that the Agriculture, Forestry, Fishing, and Hunting sector had the highest annual heat-related illness claim rate (13/100,000 full-time equivalent [FTE] employees), with a third quarter (July–September) rate of 103/100,000 FTE [2].

Heat exposure can cause nonfatal occupational heat-related illnesses, including heat rash, heat cramps, heat syncope, and heat ex-

Abbreviations: American Conference of Governmental Industrial Hygienists, (ACGIH); expert working group, (EWG); Heat Education and Awareness Tools, (HEAT); heat-related illness, (HRI); Physiological Strain Index, (PSI); social-ecological model, (SEM); United States, (US); Washington State, (WA); wet-bulb globe temperature, (WBGT).

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haustion, and can increase the risk of traumatic injuries [2–4]. Heat stress has also been reported to be associated with acute kidney injury in outdoor agricultural workers in the US [5,6] and can lead to adverse birth outcomes among heat-exposed pregnant workers [7]. In addition to outdoor workers, indoor workers exposed to inadequate ventilation or point heat sources are at risk of adverse heat health effects. The risk of adverse health effects caused by heat stress is likely to increase as mean temperatures, in addition to the frequency and severity of heat waves, are projected to increase in the future with climate change [8,9].

Risk factors for occupational heat-related illness (HRI) occur at multiple levels and include modifiable workplace factors such as absence of shade, suboptimal access to beverages and restrooms, and payment type (e.g., piece-rate payment, which incentivizes working harder and faster and minimizing breaks) [3,10]. Personal risk factors include lack of heat acclimatization, non-breathable clothing and personal protective equipment, certain medications, chronic diseases, and certain beliefs about treatment and prevention of HRI [3,11]. As with other hazardous exposures, workers with the most social and economic disadvantage are often most exposed to heat at work and may also lack adequate access to home and community cooling opportunities or other means to address exposures and health effects [12]. Further, many risk factors for adverse heat health effects are beyond the control of an individual worker and require policy or other systemic change.

Several approaches to prevent adverse occupational heat health effects have been developed. Interventions emphasizing water, rest, and shade at work have shown promise, including in preventing adverse heat health effects in sugarcane workers in Central America [13,14]. Research suggests that locating port-a-potties near outdoor agricultural workers may support hydration by reducing barriers to taking breaks to urinate during a work-shift [10]. Certain personal cooling interventions show promise in agricultural settings [15]. California and Washington are the only two US states with outdoor occupational heat rules intended to prevent HRI [16–18].

Although risk factors for adverse heat health effects exist at multiple levels, within and outside the workplace, few studies have developed multi-level interventions tailored to agricultural settings or evaluated prevention interventions for outdoor agricultural workers using controlled or comparison designs [14]. Prior intervention studies include those focused only on the workplace setting [14] or on one level of prevention (e.g., personal cooling strategies) [15] or those without control or comparison groups (e.g., when evaluating the effectiveness of policies) [19]. With input from stakeholder and community advisors, we used a social-ecological model and technology acceptance model to develop a multi-level heat prevention approach (heat education and awareness tools [HEAT]). This paper describes our approach to evaluate the effectiveness of the HEAT approach in reducing adverse heat health effects for outdoor agricultural workers.

2. Methods

In the following subsections, we describe the development of the HEAT intervention and the procedure for evaluation of the HEAT intervention. The HEAT intervention study builds upon longstanding relationships with Northwest US agricultural stakeholders and communities via the Pacific Northwest Agricultural Safety and Health (PNASH) Center to address concerns expressed by workers about health effects of working in the heat [10,11]. Founded in 1996, the PNASH Center is dedicated to the prevention of illness and injury among agricultural producers, workers, and their families and serves Alaska, Idaho, Oregon, and Washington (WA). In addition, the study partners with the Northwest Communities' Education Center (NCEC)/Radio KDNA, a Spanish language public radio station that aims to help communities overcome barriers of literacy, language, discrimination, poverty, and illness. The research team included research staff from PNASH (P·P., J.C.) and NCEC/Radio KDNA (E.T.) that live and work in agricultural communities in WA. University of Washington researchers provided scientific oversight to all research team members, including quality assurance and training for all procedures.

2.1. *Description, design, & development of HEAT intervention*

2.1.1. *Conceptual framework*

We used a social-ecological model (SEM) approach (Fig. 1a) to inform the development of our multi-level intervention, with the underlying premise that addressing risk factors at only one level (e.g. community/housing, grower/supervisor, interpersonal, or individual) is not sufficient [20,21]. SEM approaches have been increasingly used in studies aimed at preventing adverse health effects [22] in working populations [20]. Recent work also underlines the importance of addressing occupational and non-occupational factors with the goal of improving well-being [23,24]. Though intervention approaches should ulti-

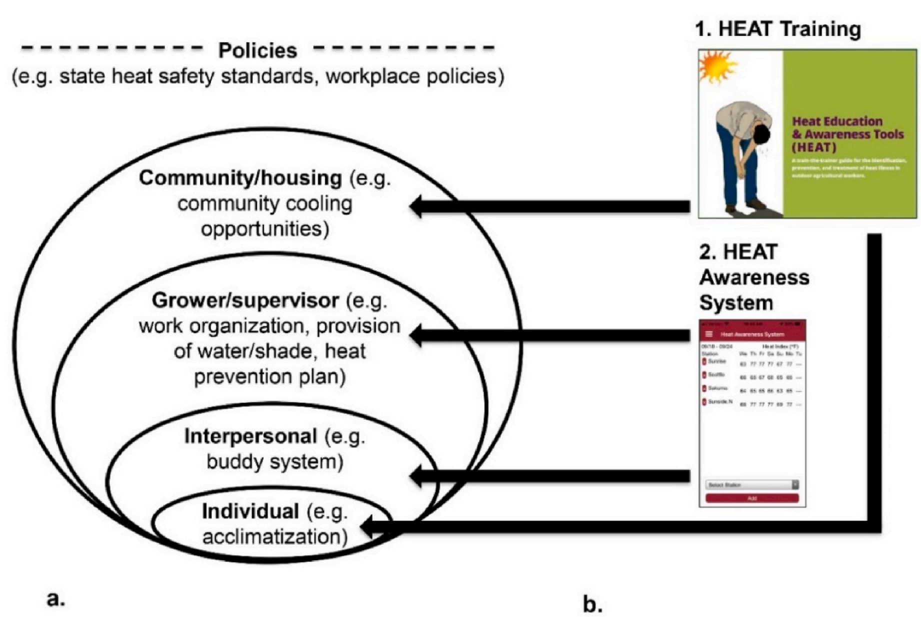

Fig. 1. a. Adapted social-ecological model for the prevention of adverse occupational heat health effects. **1b**. HEAT intervention components.

mately address overarching policies or other systemic changes, we did not directly address policy changes in our study. Content included in the HEAT intervention was based on health-based guidance from the scientific literature and evidence-based guidelines.

2.1.2. 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 [25]. 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 (Fig. 1b).

2.1.3. HEAT training

HEAT training was developed using a relational and engaged approach in the language of preference of the target audience. Relational approaches enhance inclusion by encouraging sharing of information and perspectives and have been shown to be associated with higher job satisfaction [26], which is associated with improved occupational health outcomes [27]. Engaged approaches involve participatory activities, as more active participation in health and safety training has been shown to be more effective [28]. Though HEAT training was delivered to agricultural workers by research staff in this study, HEAT training was designed to allow delivery by supervisors and other educators ('train-the-trainer' approach). A HEAT training facilitator's manual has been developed in English and Spanish (**Supplementary material I**).

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 (Fig. 1) and covers the following topics: types of HRI and treatments, risk factors for HRI, 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 HRI prevention in Latinx agricultural workers recommends that training should address beliefs, especially beliefs about HRI treatments that may not protect health, in order to be most effective [11]. These findings, as well as information about the increased risk of traumatic injury with increasing heat exposure [21], were integrated into the HEAT training. The training also complies with Washington State's Outdoor Heat Rule for Agriculture training requirements [17]. 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.

2.1.4. HEAT awareness application

We partnered with Washington State University's AgWeatherNet Program to develop a HEAT awareness mobile application that links current and forecasted weather information with health and safety messages tailored to agriculture. Application development incorporated elements of the Technology Acceptance Model, including perceived usefulness and perceived ease of use, which correlate with users' actual use, and other external factors that influence attitude and intention to use technology [29]. We sought to optimize usefulness and ease of use by incorporating iterative feedback from the EWG during HEAT awareness application development. We addressed ease of use and external factors by developing the application within AgWeatherNet's existing platform. AgWeatherNet maintains a network of over 180 professional weather stations located mostly in the irrigated and agriculturally productive regions of eastern WA and supports web and mobile platforms with weather-related crop decision support tools [30]. AgWeatherNet is a trusted source of weather information for crop decision support that is already used by growers throughout the region.

During the study period, the HEAT awareness application was provided in English or Spanish to HEAT study intervention group supervisors. We provided the HEAT awareness application to the supervisor who directly supervised each crew, and was with the crew, over the season. Research staff assisted intervention group supervisors in downloading the application to their mobile devices and selecting weather stations of interest (e.g., closest to their worksites). Research staff trained supervisors how to view current heat indices as well as maximum daily heat indices forecasted over the following week. We designed the application to notify supervisors about hot weather conditions that might increase the risk for adverse health effects for workers through push notifications, coupled with color-coded risk-level messages. Messages contained information tailored to the agricultural industry about workers' risk for adverse heat health effects and how to prevent adverse heat health effects, such as scheduling work during cooler parts of the day, depending on the weather conditions.

We calculated heat indices for the HEAT awareness application from temperature and humidity using Rothfusz's modification of Steadman's work [31]. Forecasted heat indices were based on forecasted maximum daily air temperature and minimum daily humidity, since temperature and humidity are inversely related. We sent notifications to participating supervisors one and six days before a forecasted heat index of 91 °F or higher. A threshold of 91 °F corresponds to the American Conference of Governmental Industrial Hygienists (ACGIH) Heat Stress Threshold Limit Values (TLV) [32], assuming workers wear regular work clothes without extra layers, are performing moderate physical work, and are working with an allocation of work in a cycle of work and recovery of 75–100%. Correspondence between ACGIH wet-bulb globe temperature (WBGT)-based guidance and heat indices was determined using published methods [33]. In addition to ACGIH guidance, which is consistent with National Institute for Occupational Safety and Health guidance, we also considered guidance from the Occupational Safety and Health Administration (OSHA) [13] in developing risk levels and messages, where 91 °F corresponds to a moderate level of risk. Between a heat index of 80–90 °F, suggested actions for heat prevention were available in the application, but push notifications were not sent out below 91 °F to minimize users receiving too many notifications during hot periods. HEAT awareness system risk levels and messages are shown in Supplementary material II.

2.2. Study design

We designed the HEAT evaluation study as a parallel, comparison, group intervention study to evaluate the effectiveness of the HEAT intervention, consisting of worker training and a supervisor heat awareness application, on reducing adverse heat health effects for agricultural workers across a growing season. The study flow for worker participants is shown in Fig. 2 and described in subsequent subsections. The study took place over the summer season (June–August) 2019.

2.3. Study setting, recruitment, & eligibility

The study team recruited farmworkers from eastern and central WA, a productive agricultural region with a largely Latinx workforce, from workplaces that agreed to participate in the study. Agricultural workplaces that employed workers to do agriculture and agriculture support tasks from June through August were eligible to participate in the study. Agricultural workplaces were recruited using various ap-

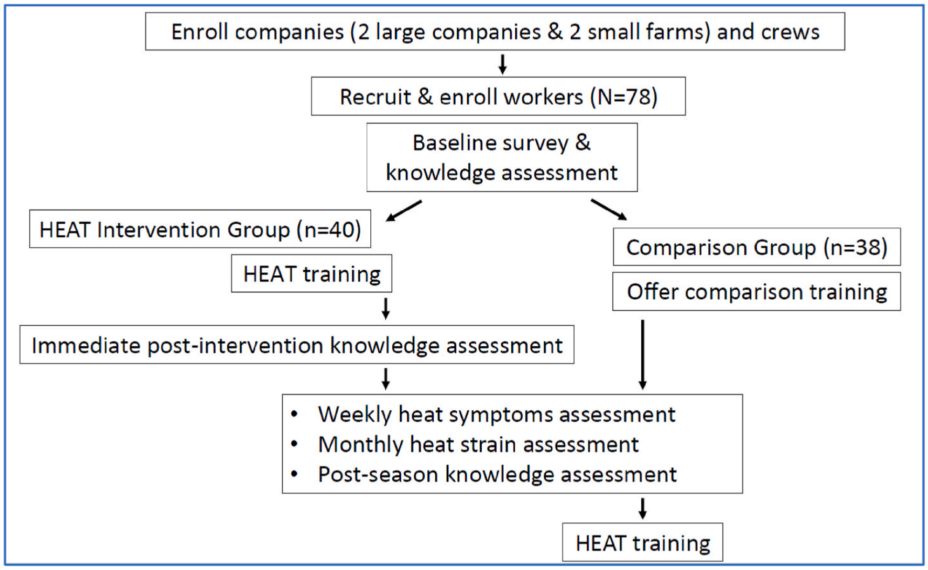

Fig. 2. Study flow for worker participants, June–August.

proaches, including through contacts of the PNASH Center's research staff, listserv emails, and through WA agricultural organizations. Once workplaces were identified, workplace representatives (e.g., owners, managers) were contacted by phone and/or email, and study researchers shared additional information about the study. The research team then visited workplaces that were interested in participating, established agreements of the workplace to participate, obtained information about the workplace, and recruited workers from work crews for the study. Farmworkers and supervisors at workplaces who agreed to participate, were 18 years or older, spoke English and/or Spanish, and planned to work for the same workplace during the summer season (June–August) were eligible to participate. Due to study resource limitations, only participants who spoke Spanish or English were eligible to participate. All workers working directly for farms, including seasonal workers and US H-2A guest workers, were eligible to participate. The H-2A program allows agricultural employers to hire workers from other countries on temporary work permits for agricultural jobs.

2.4. Intervention allocation

Research staff allocated crews of participating workers within each workplace to intervention or comparison groups (Fig. 2). Research staff were trained to randomly allocate crews to intervention and comparison groups using simple randomization (coin flip). Workers were not aware of which group they are allocated to, but research staff assigning crews to groups were aware of assignments. Workers in the intervention group received HEAT training, and supervisors in the intervention group received the HEAT awareness mobile application and training on how to use it. The comparison group of workers was offered an alternative occupational training on pesticide safety or sexual harassment prevention. These two topics were selected because of the availability of training materials. Comparison group supervisors were not the same as the supervisors overseeing intervention group crews, and comparison group supervisors were not provided with the HEAT mobile application. After the post-season assessment, comparison group crews were offered HEAT training.

2.5. Measurements

After obtaining informed consent, research staff asked farmworkers to complete a baseline survey (**Supplementary material III**) and knowledge assessment, and supervisors to complete a baseline survey (Fig. 2). The baseline farmworker survey included questions about demographics, health, work, and community factors relevant to heat exposure and health effects. Directly after the training, workers in the intervention group completed a post-training knowledge assessment. In both groups of workers, symptoms were assessed approximately weekly and physiological monitoring for heat strain was conducted at the worksite approximately monthly during the summer season (e.g., June, July, and August). At the end of the summer season, workers in both groups completed a post-season knowledge assessment, and supervisors in both groups received a post-season survey.

2.5.1. Primary outcomes

The primary outcomes were: 1) heat strain, the body's physiological response to heat stress; and 2) HRI symptoms. We computed the Physiological Strain Index (PSI), which was developed to evaluate heat strain [34], using baseline heart rate and core body temperature and continuous heart rate and estimated core body temperature during the work shift. The severity of heat strain is expressed on a scale from 0 to 10, with two PSI points per category (i.e. minimal [PSI 1–2], low [PSI 3–4], moderate [PSI 5–6], high [PSI 7–8], and very high [PSI 9–10] severity) [34]. We measured heat strain using baseline and continuous heart rate and baseline personal aural (ear) temperature on monthly heat strain assessment days. Continuous heart rate was measured using Polar® H10 heart rate chest band monitors (Polar Electro USA, Lake Success, NY, USA) worn by participants throughout their work shift. Research staff assessed baseline heart rate and baseline aural temperature with manual pulse measurements and Braun® Thermoscan IRT 4520 thermometers (B.Braun, Bethlehem, PA, USA), respectively, before participants started their work shift. We calculated estimated core body temperatures from baseline aural temperature, to which we applied a standard adjustment for differences between core and aural temperatures [35], and continuous heart rate, using a validated algorithm [36,37].

We assessed heat symptoms every week using a short survey conducted in Spanish or English that included questions about HRI symptoms experienced over the past week (Supplementary material IV). The survey is based on a previous survey that was evaluated for validity and reliability in Latinx farmworkers [10] and was administered by telephone by research staff or mobile phone application.

2.5.2. Secondary outcomes

In addition to primary aims, we secondarily aimed to: 1) evaluate the effectiveness of the individual-level worker heat training component; and 2) describe how the workplace supervisor-level heat awareness mobile application affected supervisors' practices to reduce the risk of workers experiencing adverse heat health effects. Corresponding secondary outcomes were: 1) individual worker heat knowledge; 2) and supervisor work practices. At the beginning and end of the season, all participants complete a HEAT knowledge assessment in English or Spanish consisting of twelve multiple-choice questions covering content in the HEAT training (Supplementary material V). Intervention group participants also completed the knowledge assessment immediately after HEAT training, as described in Fig. 2. The supervisor survey collected pre- and post-season information on work practices, including heat prevention practices. Supervisors of intervention crews were asked about their use of the HEAT awareness application.

2.5.3. Covariates

We collected data on covariates that we determined *a priori* may serve as confounders or precision variables in our main analysis. In the baseline worker survey, we asked participants about demographic, health, work, and community factors that may be related to heat knowledge and HRI, including age, gender, education, chronic health conditions, previous HRI, English and Spanish literacy, cooling and break opportunities at work, distance to the toilet at work, previous HRI training, and ability to cool down at home or in the community. Research staff also recorded information about workplace size and about which workers were part of the US H-2A guest worker program. In addition, field staff observed hours worked, breaks, clothing, and hydration practices, and workers completed a brief survey in English or Spanish on heat strain assessment days (**Supplementary material VI**). Workers also answered questions on weekly questionnaires about work tasks, crops, and payment type (e.g., piece-rate, hourly).

In addition to heart rate chest band monitors, participants wore Kestrel DROP D2 environmental data loggers (Kestrel® Instruments, Boothwyn, PA, USA) to measure personal ambient temperature and humidity during heat strain assessment days. Heat indices were calculated from temperature and humidity using Rothfusz's modification of Steadman's work [31].

2.6. Human subjects

2.6.1. Informed consent, incentives, and return of results

The University of Washington Human Subjects Division (HSD) approved all study procedures, including plans for informed consent, how personal information about potential and enrolled participants were collected, shared, and maintained to protect confidentiality before, during, and after the study, data access and management, and communication of study results. All participants provided written informed consent prior to participation in the study (**Supplementary material VII**).

The HEAT study provided participants incentives to account for their time participating in the study in the form of $50 for each month they participated in the study, up to $150 total for participating in the months of June, July, and August. Preliminary results of individual measurements were returned to participants, and de-identified aggregate summaries of descriptive results were disseminated to participants and collaborating workplaces. The HEAT study is registered with ClinicalTrials.gov.

2.6.2. Data safety monitoring

The HEAT study was determined to be a minimal risk study by the University of Washington Human Subjects Division, which approved the study and its data safety monitoring plan. Agricultural workplaces in WA are already required to have emergency response plans and, as part of the outdoor heat rule specifically, procedures for moving or transporting an employee to a place where the employee can be reached by an emergency medical service provider, if necessary [16,17]. In addition, the physician PI (JTS) and research team created a plan for local healthcare provider follow-up with individuals for whom other non-acute health concerns were noted on physiological monitoring.

2.7. Statistical considerations

2.7.1. Sample size and power calculations

We performed a simplified analysis to estimate the power to detect a meaningful difference in our primary outcome, PSI, as prior information on effects of all covariates is not available. Our analysis was based on Monte Carlo simulations for a two-way ANOVA model having workplace and intervention factors, with workers for each workplace split into two crews, one randomized to the intervention group and one to the comparison group. We computed power for studies with three workplaces (one small and two large) and three study sizes in terms of numbers of workers, small (6–12 workers/crew; 60 workers total), medium (10–16 workers/crew; 84 workers total), and large (12–20/crew; 104 workers total). The simulations use worker-to-worker standard deviation estimates for PSI measurements from our 2013 and 2015 pilot data in the Central/Eastern WA area. The analysis compares average PSIs of participants in the intervention and comparison groups in the ANOVA model accounting for differences between workplaces. Based on worker-to-worker standard deviation in PSI of 1.0–1.2, the smallest study size achieves estimated power of 80% at a mean difference in PSI of about 1.2 for a worker-worker standard deviation of 1.0, and at a mean difference in PSI of about 1.4 for a worker-worker standard deviation of 1.2. The larger sample sizes achieve 80% estimated power at lower mean differences. We recruited 87 workers from six crews, with 78 workers (38 intervention group and 40 comparison group participants) participating in at least one field monitoring day, allowing sufficient power to detect meaningful changes in PSI levels between the groups.

2.7.2. Data analysis plans

The primary hypothesis is that workers who are randomized to receive the HEAT intervention will exhibit less heat strain compared to workers in the comparison group.

2.7.2.1. Primary analyses. We plan to assess the association between work shift PSI and group status (intervention versus comparison, with group assigned using intent-to-treat) using linear mixed effects models addressing temporal (weekly) variation and random effects for workers. The model will include a term for personal ambient work shift heat index and employer, as fixed effects. We will also explore an interaction between heat index and group assignment to assess the likelihood that the intervention effect occurs during periods with the highest heat conditions. A similar generalized mixed model will be used to assess the binary outcome of whether or not workers exhibited heat strain symptoms over the past week. Given the relatively small nature of the intervention study, we will additionally consider adjusting for the following potential confounders in the analysis: 1) individual: age, gender, education, previous HRI, chronic health conditions (e.g., diabetes); 2) work: work task, crop, H-2A status, previous HRI training, piece rate payment, cooling opportunities, being allowed to take extra breaks, length of time to walk to the toilet; 3) community: ability to cool down at home or in the community.

2.7.2.2. Secondary analyses. In secondary analyses, we will conduct the primary analysis using estimated core body temperature as the outcome instead of PSI. In addition, we will evaluate the difference between pre- and post-knowledge scores in the intervention group using the paired Wilcoxon signed rank test. We will evaluate the difference in knowledge scores between the post-season and pre-season knowledge evaluations between the intervention and comparison group using the Mann Whitney *U* test. We hypothesize that workers who receive HEAT training will have greater pre-post increases in knowledge than those that do not. Finally, we will describe pre- and post-season supervisor survey responses about heat prevention practices in the intervention and comparison groups.

2.8. Dissemination of findings & evaluation

We developed dissemination and evaluation plans with input from research team members and members of the EWG and technical advisory group. The audiences for dissemination includes workers, growers, government agencies, community organizations, health and safety educators, and scientific researchers. The formats for dissemination include presentations and tailored summaries at workplace safety meetings, health fairs, local industry, and scientific conferences, and short reports, newsletters, programming for Radio KDNA, social media campaigns, train-the trainer sessions, and peer-reviewed scientific publications. In addition, the HEAT training is publicly available at the PNASH website, and the heat awareness application will be available to subscribers at the AgWeatherNet website. During dissemination, we will conduct evaluations to collect information on reactions to the HEAT intervention and plans for implementation, including motivation, integration into current safety programs, and intentions for sustaining the intervention.

3. Discussion

To our knowledge, this is the first study to evaluate the effectiveness of a multi-level heat prevention intervention on health effects from heat for outdoor agricultural workers. Though approaches to prevent health effects from heat have been developed [11,13–19], additional information about the effectiveness of intervention approaches in different field settings using controlled or comparison designs is needed to better support evidence-based decision-making. The HEAT intervention is grounded in a social-ecological model of prevention, developed with input from agricultural workers and other stakeholders, tailored to agricultural settings, and based on existing evidence- and health-based recommendations for heat prevention [32]. We aim to advance the literature by providing insight into the effectiveness of the multi-level HEAT intervention on physiological heat strain and HRI symptoms for agricultural workers.

To maximize the chances of successful research translation, the HEAT intervention was developed as practical solutions and preventative strategies that were shaped and vetted by advisory stakeholders, including agricultural industry representatives and farmworkers. The participatory training component of the HEAT approach was intended to support workers in making choices that will minimize their risk for HRI, while the heat awareness mobile application was intended to address risk factors that are beyond the control of individual workers but achievable for workplaces. We worked with bilingual and bicultural research staff who have successfully engaged with agricultural workers and demonstrated their ability to build trust with participants and employers [10].

We assessed both objective (estimated core body temperature) and subjective (self-reported HRI symptoms) metrics of health effects of heat for our primary analyses. Though in previous research we utilized ingestible temperature sensors, which required participants to swallow a pill-sized sensor, to assess core body temperature [38], we sought a less invasive objective approach to estimate core body temperature that was more acceptable to participants for the HEAT intervention study. We used a published algorithm [36] to estimate core body temperature from baseline temperature and continuous heart rate data collected using chest bands. This algorithm has been validated in military field settings [37], and we are conducting separate analyses with previously collected data to compare the algorithm output to ingestible sensor data in agricultural workers performing field work, which will help to inform interpretation of results for this study. We also collected self-reported HRI symptoms, which provide important insight into perceptions of heat exposure and effects. Symptom awareness is important for early recognition to prevent more severe HRI [39].

This study has several potential limitations. For the symptoms outcome, recall bias may occur, and heat exposure could conceivably affect memory [40]. We selected a one-week time-frame to minimize recall bias [41], and we do not expect differential recall bias between the intervention and comparison group. We included both subjective (symptoms) and objective (heat strain) outcomes in our study. Collection of both objective and subjective measures will allow us to examine the relationship between objective and subjective measures of heat strain. In addition, our study was not resourced to include non-English and non-Spanish speaking workers. Future, larger studies should include non-English and non-Spanish speaking workers. We were not able to address potential crossover that may have resulted from interaction of intervention and comparison participants (e.g., within housing or in the community). However, we conducted an intention-to-treat analysis, and any crossover is expected to result in a conservative (smaller) effect of our intervention. Finally, our study took place in the Northwest US, and results may not be generalizable to all agricultural workers beyond the Northwest.

Agricultural workers, who play an essential role in food production in the US, are at elevated risk of adverse health outcomes from heat exposure, particularly when performing physically demanding harvest activities during warm summer months [1]. This risk may increase as mean temperatures, in addition to the frequency and severity of heat waves, increase in the future with climate change [8,9]. We designed our study to aid in addressing this growing population health threat, respond to concerns expressed by workers about working in the heat [10], and, when coupled with policy and systemic change, ultimately enhance climate resilience for agricultural workers. Our study will contribute information about the effectiveness of the multi-level HEAT intervention on reducing adverse heat health effects for agricultural workers, and we anticipate that the HEAT approach could be adapted for other working populations.

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Author's contributions

JK, PS, and JTS contributed to the conceptualization and methodology of the work; ECS, ET, PP, JC, and MB contributed to the investigation; JK, ECS, JC, DM, PS, and JTS contributed to plans for formal data analysis; JTS, ECS, and JK drafted the original manuscript; JK, ECS, ET, PP, JC, MB, DM, PS, and JTS provided edits and revisions to the manuscript. All authors read and approved the final manuscript.

Data availability statement

De-identified data and statistical code will be made available upon request and/or will be available in a publicly accessible data repository.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.conctc.2021.100795.

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