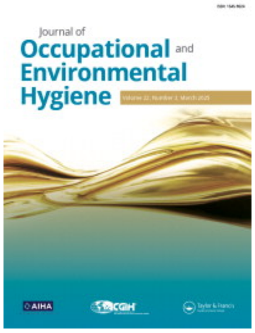


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# Understanding and perceiving heat stress risk control: Critical insights from agriculture workers

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**ABSTRACT**
Software-driven wearable technologies are emerging as a control for heat-related illnesses. Such devices collect biometric data and estimate risk noninvasively. However, little is known about workplace implementation strategies and stakeholder acceptance of the devices. As part of a mixed-methods pilot study to evaluate the feasibility of wearable technologies, the authors invited six agricultural workers with no device experience to participate in a semi-structured focus group, after wearing two devices (e.g., MākuSafe, Des Moines, IA, United States; SlateSafety, V2, Atlanta, GA, United States) for a standard work week. The focus group was separated into two parts: the first assessed the overall understanding of heat stress, and the second captured workers' perceptions of the wearable technologies. For each topic, the authors extracted relevant themes that describe farm workers' general understanding of heat hazards and worker interaction with wearable technology used in heat-related risk. These themes provide relevant answers to the questions outlined in the semi-structured questionnaire that can guide future research into the use of these devices in occupational settings. Wearable technologies continue to be used to control heat-related illnesses. Therefore, it is critically important to gather key strategies for employer implementation and user-interface considerations.

**KEYWORDS**
Environmental exposure; heat management; heat stress disorders; occupational health; qualitative research; wearable electronic devices

## Introduction

Occupational heat stress remains a prevalent hazard in industrial settings. In 2023, Nebraska identified 28% of all emergency department visits for heat-related illnesses where the activity before the visit was noted as a work-related activity (Rachael Birn, personal communication, March 29, 2024). Further, Nebraska incurred a heat death rate of 1.97 per 1 million workers, ranking the state among one of the highest reportable rates in the United States (Bogage and Tan 2023). Workers in hot environments, such as firefighters, bakery workers, farmers, construction workers, miners, boiler room workers, and factory workers are at risk of heat stress (National Institute for Occupational Safety and Health 2020).

The agriculture industry consistently ranks among the highest rates for workplace injuries and illnesses, both nonfatal and fatal. Within the agriculture, forestry, fishing, and hunting industries, the most recent available data indicate the rate of nonfatal injuries and illnesses was 4.2 per 100 full-time equivalent workers in 2023 (Bureau of Labor Statistics 2023) and the fatal work injury rate was 18.6 per 100,000 full-time equivalent workers in 2022 (Bureau of Labor Statistics 2022). Agriculture workers are highly susceptible to heat-related illnesses from outdoor exposure to extreme temperatures. Heat-related illnesses impact worker health and can result in medical emergencies. One study found that agriculture had more than 35 times the risk of heat-related death in comparison to other referent groups (Gubernot et al. 2015). Some research has evaluated how global temperatures and extreme heat events impact agricultural workers (El Khayat et al. 2022). In addition, research has identified that

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outdoor agricultural workers laboring in warm ambient conditions are at an increased risk for traumatic injuries (Spector et al. 2016). Common mitigation practices for heat-related illnesses aim to follow the hierarchy of controls (National Institute for Occupational Safety and Health 2023) and employ a fit-for-duty workforce. Given a persistently dangerous industry and increasing global temperatures, heat impacts are progressively concerning for occupational health practitioners.

It has been documented that workplace-based physiological monitoring is key to identifying workers who are at high risk for heat illnesses (Mac et al. 2021). Software-driven wearable technology that collects individual biometric data has been considered for assisting in the prevention of heat-related illnesses. Biomonitoring use in agriculture settings has been evaluated and found that physiological monitoring outside the confines of a laboratory setting is feasible (Mac et al. 2017). Moreover, affordable measurements to assist in the prevention of heat-related illnesses can help develop compelling messages advocating for policy to protect vulnerable working populations (Hertzberg et al. 2017). Though physiological monitoring trends may be appealing, other considerations emerge regarding device comfortability, user interaction, privacy, and difficulties in company implementation. Employers must consider these challenges before digital transformation can be used to reduce heat stress risk. To date, the authors have not identified any studies that examine practical implementation strategies for the MākuSafe (Des Moines, IA, United States) and the SlateSafety, V2 (Atlanta, GA, United States), both heat-related wearable devices. To address this gap, the authors conducted a mixed-methods pilot study with a semi-structured focus group to assess the feasibility of using wearable technologies in agriculture. The objective of this qualitative study was to identify potential heat-related risk factors and provide insights related to user interfaces with software-driven wearable technologies.

## Methods

### Design

This qualitative study is part of an evaluation of wearable technologies used to assess occupational heat-related risk in agricultural workers. The overall project employed a mixed-methods approach to evaluate the feasibility of wearable technologies and workers' perceptions toward technology implementation. As part of the overall study, study participants (farmworkers) wore two devices (e.g., MākuSafe, Des Moines, IA, United States; SlateSafety, V2, Atlanta, GA, United States) throughout a standard work week. The MākuSafe wearable device is used to assess environmental conditions by collecting data on humidity, temperature, noise, air quality, and light. The SlateSafety V2 armband is used to assess individual heat strain by collecting physiological biometrics such as heart rate and estimating core body temperature during daily work activities. The SlateSafety V2 armband has been previously evaluated in laboratory settings against other measurement techniques (Callihan et al. 2023; Ibrahim et al. 2023). These devices were selected specifically based on investigator expertise and their known performance. Further information and details on each device can be found on their websites (https://slatesafety.com/products/band-v2/; https://makusafe.com/hardware/).

During the data collection period, participants arrived at a central location in the morning to check out their devices. A member of the research team placed the devices on the participants' arms and ensured connectivity before work began. At the end of the work shift, participants would drop off the devices for charging overnight. The devices were reconnected to the base station and/or charging station. Once connected to the base station, these data synced to the cloud for data retrieval and storage.

At the end of the data collection period, the research team conducted a focused group discussion with the workers to discuss potential heat-related risk factors and perceptions regarding the wearable technologies. The research team comprised experts in industrial hygiene, heat stress, wearable technology, health economics, environmental exposures, and epidemiology. All research team members had significant experience with conducting, analyzing, and interpreting qualitative data, including focus group discussions.

### Participants

The research team recruited farmworkers in Nebraska, United States. Recruitment was performed through the University of Nebraska's flagship university in Lincoln. A purposive sample was recruited to participate in a mixed-methods study in September 2023. The study included six participants who work in various roles in facilities management and cow/calf production. Each participant received lunch and a $25 gift card for participating in the focus group component of the study. The study protocol was approved by the University's Institutional Review Board (IRB # 0229-23-EP). Before data collection, three members of the research team met with participants to provide an overview of the project and study protocols. After the introductory meeting, the research team provided a copy of the study protocols and allowed several days for each worker to consider participation. After the consideration period, the investigators and workers met so the remaining questions could be answered and to obtain written informed consent from participants.

### Procedures

The focus group discussion was performed in a conference room located at the job site over the lunch break. The investigators followed a semi-structured framework questionnaire (see Supplemental Material). The focus group was separated into two parts: Topic 1 assessed participants' overall understanding of heat stress risk factors; and Topic 2 captured workers' perceptions of the wearable technologies. The authors recorded the audio from the in-person focus group discussion and used the automatic transcription service provided by the recording technology. The lead author (R.C.) conducted the focus group and the corresponding author (K.K.) took written notes. The recording and transcription were reviewed and cleaned for accuracy by the lead author. Transcripts were not returned to the participants for comments and/or corrections. The lead author reviewed the recording several times to ensure the factual accuracy of the participant's comments.

### Data analysis

The authors performed reflexive thematic analysis (Braun and Clarke 2019, 2021; Braun et al. 2019), following a six-phase analytical process (Braun and Clarke 2006). The authors followed practical guidelines (Byrne 2022) to extract relevant themes from the focus group session, starting with (1) familiarization with the data by listening to the recording and cleaning the transcript for accuracy. Upon the cleaning process, initial notes were made using the "comments" function in Microsoft Word (Office 365, Version 2307). After reviewing the transcript several times, (2) the authors generated the initial codes using the "comments" function in Microsoft Word. The authors coded the participant responses related to the semi-structured questionnaire. The codes were copied and tracked in Microsoft Excel. All codes were copied into a second Excel tab to start generating themes. The next phase shifted toward aggregate code analysis and interpretation to (3) search for themes from the codes. The initial themes provided context to develop two mind-maps to conceptualize relevant themes and sub-themes. The authors separated the mind maps into Topic 1 and Topic 2 from the semi-structured questionnaire. During the (4) theme review process, the authors combined the separate mind maps into an overall thematic mind map (MindMup, Sauf Pompiers Limited, United Kingdom). In this phase, the authors assessed the quality, boundaries, meaningfulness, and coherence of the themes (Byrne 2022). In the final analysis, (5) the authors defined and named the themes. This process further solidified the themes in the mind map (see Supplementary Material). Before (6) producing the report, the authors established the theme order. The order follows the semi-structured questionnaire to best align with the focus group session sequence.

## Results

The six participants included an electrician, a heavy equipment operator, two carpenters, a landscaper, and a husbandry manager who oversees agricultural technicians. All participants were male between 26 and 65 years of age. Between the two topics, six overarching themes were developed. The authors further categorized these themes into 19 sub-themes. These themes and sub-themes are provided in Figure 1. For each topic, the authors extracted three themes from the dataset. These themes provided relevant answers to the questions outlined in the semi-structured questionnaire.

### Topic 1 themes: Heat stress awareness, control measures, and medical response

#### Theme 1: Heat stress and heat strain control measures

When asked about how heat stress influences daily activities and heat stress control, the participants reported schedule adjustments were the primary control. The group discussed their ability to shift priorities to do strenuous work activities in the cooler parts of the day. The group further emphasized their inability to perform animal work (e.g., cow/calf production) during hotter conditions. The emphasis on caring for the animals was prevalent throughout the discussion. As such, it was recognized that heat impacts animals in similar capacities as humans. The ability to use shift adjustments was demonstrated by the following comment.

> There are certain things I can do on different days, and I'll put the inside work during those super-hot days. And then other days when it is not as hot,

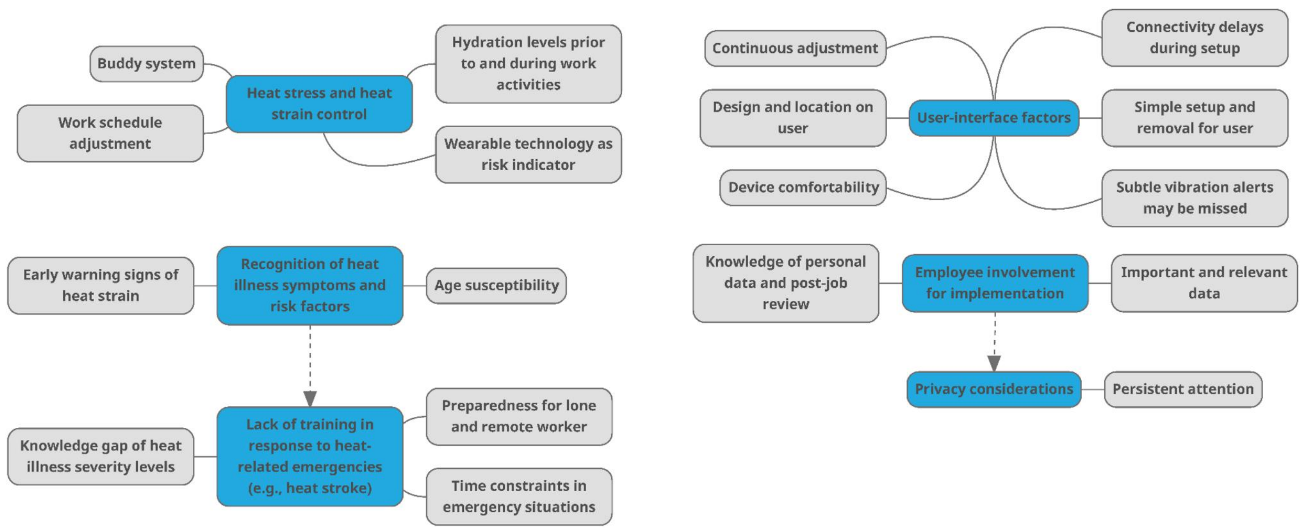


**Figure 1.** Mind map of themes and sub-themes from focus group.

> I can do outdoor activities. (Landscaper, Facilities Management)

The participants understood the importance of hydration levels before and during work activities. In particular, the group discussed supplemental hydration strategies using sports drinks and/or electrolyte drinks. The participants identified supplemental hydration drinks were an important consideration for pre-work and potential hydration maintenance. The facilities had water readily available onsite and when working in remote areas, the employees carried water with them. The group further emphasized that a standard pack of water bottles (16.9 ounces) was available.

The participants emphasized the "buddy system" as another control strategy. The employees frequently worked in pairs or groups throughout the day. Each worker indicated that they observed their coworkers for signs of heat-related illnesses. The employees frequently communicated and checked on their coworkers throughout the day. The communication consisted of encouraging coworkers to take frequent breaks and stop work activities during periods of elevated heat risk. The stop-work ability was demonstrated by the following comment.

> I called [(co-worker)] to come in. Otherwise, she would have been out in it. I mean, it was really hot. I told her to just quit. (Carpenter 2, Facilities Management).

The final heat stress control was reported in Topic 2 themes but emphasized that wearable technologies can be used as a risk indicator. The devices could be used to show individual exertion levels and oversee triggering threshold limits. Many of the participants mentioned their habitual nature to "push through the heat" and complete the job tasks. The participants mentioned the devices can be used as a tool to indicate stopping points.

### *Theme 2: Recognition of heat-related illness and risk factors*

Participants described early warning indicators of heat strain and understood symptoms that could be treated with first aid. The indicators mentioned included dehydration, excessive sweating, headaches, and age-related risk factors. The group seemed to understand the symptoms and severity of heat exhaustion. Symptoms of heat exhaustion can include feeling faint, dizzy, elevated heart rate, and nausea (Larrañaga 2011). In particular, the group discussed heat cramps and exhaustion symptoms. Further, the group understood and identified first-aid response strategies to manage a coworker's heat-related incident. The group articulated the focus on core body temperature and cooling mechanisms. The participants noted methods to rapidly reduce core body temperature. Specifically, the group discussed moving coworkers to rest in a cool area and applying ice to armpits and groin.

### *Theme 3: Lack of training in response to heat-related emergencies (e.g., heat stroke)*

As identified in Theme 2, the group recognized the importance of core body temperature and cooling mechanisms. However, when asked about heat-related emergency protocols, there was some hesitation in the responses. The employees recognized standard first aid protocols but did not seem to recognize the onset of or response to emergency heat-related illnesses, such as heat stroke. When asked about requesting emergency services, the participants indicated that self-transport may be the best option due to the remote location of their facilities and worksites. Likewise, the employees reported difficulties in emergency services finding their work locations (i.e., no standard Emergency 911 address for pastures).

A participant mentioned that employees frequently engage in non-routine workdays (e.g., weekends). During these work shifts, few coworkers are on site, thus controls rely solely on self-monitoring. The participant mentioned that the only individual aware of the work shift was his spouse. However, in emergencies, individuals unaffiliated with the job site may not be familiar with the work locations. Situations with individuals unfamiliar with the work location were noted as the most dangerous heat illness emergencies.

## Topic 2 themes: Perceptions of wearable technology and user-interface

### Theme 4: User-interface factors

Overall, the group acknowledged the comfort of the devices was adequate. Some comments were related to the initial concerns of discomfort. Despite overall satisfaction, there were some comments about irritation and discomfort. The armband tightness and excessive sweating influenced irritation and discomfort during extreme temperature days. This is demonstrated in the following comment.

> And just yeah, it gets uncomfortable. I could almost see on the really hot days, that I would not want to wear it. Yeah, it was just getting uncomfortable that way. And it would get irritating for certain jobs like a water main job or something. I don't think I would wear it. (Carpenter 2, Facilities Management)

The group agreed that wearing the devices did not directly interfere with their daily work tasks. However, there were numerous comments related to the continuous adjustment of the devices. In particular, the participants reported the devices often moved around on the arm or slid out of the armband socket. These phenomena were demonstrated by the following comments,

> I've noticed it too, when the guys start sweating and using your arms, this [(SlateSafety device)] kind of moves around. And it creeps down on your arm. (Heavy Equipment Operator, Facilities Management)

> I had a little problem with this one [(MākuSafe device)]. This one sometimes gets bumped, and it comes out. It came out of the slide, I guess. I think I noticed it right away. (Landscaper, Facilities Management)

The group frequently brought up the design and location of the wearable technology. The participants felt the devices could be placed on a different part of the body or apparel location. The group asked about other devices that have different designs and functions. They asked if the two companies (MākuSafe and SlateSafety) explored options other than an armband. Participants discussed chest strap heart rate monitors. As one participant mentioned,

> Could they come up with someplace other than your biceps? 90% of the people in this room, that's what we're using most. We're always using our arms. It would be good to come up with something better and smaller. (Electrician, Facilities Management)

Much discussion explored the device alerting systems and mitigation practices. During the conversation, participants mentioned that the vibration of the SlateSafety device seemed subtle. Participants acknowledged that the alerts were imperative when implementing the devices to ensure safety and health. The investigators clarified the different alerting systems that include vibration, text messages, software, and email notifications, which were not used as part of this pilot study. The group agreed that these notification systems would be beneficial to the user and supervision. However, the group acknowledged that relying on a device vibration alone could result in a missed signal, depending on the job task.

Overall, participants agreed the devices were simple with regards to setup and removal for the user. There were a few participant connection delays during the morning setup throughout the data collection period. All setup issues were related to connectivity and poor heart rate signals.

### Theme 5: Employee involvement in implementation

Participants discussed the preferred wearable device (i.e., MākuSafe or SlateSafety) and inferred through multiple comments that relevant and important data collection is required. In general, participants preferred heat stress data evaluating individual metrics (i.e., SlateSafety). However, participants mentioned that data collection should be task-specific, and it is also important to evaluate environmental conditions. For instance, one comment related to heat stress-specific data collection stated,

> It seems like the one that picks up your heart rate and tells you that kind of stuff, would probably more viable or more telling information that is specific to your body. (Landscaper, Facilities Management)

Other comments mentioned that task-specific data collection should be considered to examine more than individual biometrics. When asked about preferences toward the devices, an employee stated,

> I think as a user, the decibel levels, when you go back and look at that, and see oh, well, that's a noise level that I didn't realize. I should be wearing hearing protection while I am doing that. (Heavy Equipment Operator, Facilities Management)

Participants acknowledged the importance of real-time data and communication about their metrics and expressed an interest in knowing how their data correlates with heat-related risk. Participants mentioned that reports of individual data would be necessary for technology implementation. When asked about final thoughts related to the devices, one participant commented,

> If we have that feedback from the device at the end of the day, or throughout the day, where we could pull it or we had the information on the computer or whatever, I mean that would be necessary, if you were going to actually, really use these devices. (Husbandry Manager, Cow/Calf Production)

Participants mentioned the importance of contemporary data review to work safely. When asked about best practices for review, the participants agreed that a visual display of the data that provides an overall summary and identifies key exceedances was preferred.

### *Theme 6: Privacy considerations*

All participants commented there were no concerns related to data privacy while wearing the devices. The related comments were that health-conscious employees generally want to know their information and would not be concerned about data privacy. Further, when asked about general oversight or concerns related to "actual worktime," all employees mentioned there were minimal concerns. There was one comment related to the general tracking of participants. The employee mentioned,

> I didn't really have any concerns about privacy and that part of it. But just wearing it, made you kind of think about, like man, I have to wear these things, and they track location and all that stuff. I don't know, I was talking to [(Agriculture Technician)] about it but I really don't do anything during the day that I'm hiding or whatever, but still that thought kind of creeps in your mind. It just makes it more conscious on, you know, they are seeing on GPS or something like that. So, I don't know. Kind of like a weird thing. (Husbandry Manager, Cow/Calf Production)

## Discussion

Heat stress mitigation practices need additional surveillance and preventative measures to protect employee health. The solution must consider future directions in occupational heat stress management that include individual variability (Notley et al. 2019). Wearable technologies can be used to monitor physiological impacts and environmental conditions and assess heat strain during job tasks. These devices can provide real-time assessments that allow immediate hazard mitigation and productivity maintenance (Notley et al. 2019). The industry needs a practical solution that balances risk and productivity. To address this need, the authors conducted a mixed-methods pilot study that included a focus group discussion on heat stress risk factors and captured wearable technology implementation strategies, barriers, and perceived improvements. The study findings add to the existing heat stress literature by examining workers' identification of risk factors and perceptions of emerging technologies. Overall, the workers seemed to have a general understanding of occupational heat risks. The workers discussed controls, symptoms, and personal risk factors, which led to a discussion on first-aid identification and heat-related emergency response. The discussion finished with perceived improvements and challenges related to heat-specific wearable technology implementation. These findings suggest practical feedback that must be considered during the technology adoption process.

### *Topic 1: Heat stress awareness, control measures, and medical response*

The participants had a general understanding of basic recommendations and common practices for heat stress (National Institute for Occupational Safety and Health 2018). Work adjustment was used as the primary control. Further, their management supported work adjustment and safe work practices. This understanding of management support sheds light on an important aspect of controlling occupational heat stress, as leadership provides sufficient resources to implement and maintain safety and health (Occupational Safety and Health Administration 2016). However, some research suggests that poor management practices and inflexibility of supervisors are prevalent in complaints regarding heat exposure (Hansen et al. 2018). Similarly, the lack of regular breaks has been shown as a potential barrier to heat illness prevention (Fleischer et al. 2013). Deriving from poor leadership, the inability to take breaks and continuing to work excessive hours in the heat could negatively impact workers' susceptibility to heat-related illnesses. As such, workers must be empowered to selfregulate and recover as necessary. Within the study population, we saw the importance of supervisor and peer support for recognizing and minimizing heat-related illnesses. Future research should explore the relationship between organizational safety culture and heat stress management. An interactive relationship can attest to advanced safety and health programs.

Dehydration was considered an important risk factor before and during work activities. Participants acknowledged accessibility to water and taking an adequate water supply with them during remote work activities. Each facility had water available for employees. It was commented that up to one liter of water was taken in the field by each worker and was readily available for consumption. Most of the employees were scheduled for routine breaks mid-morning, which allowed for fluid replenishment. However, a scheduled break after lunch break was not observed throughout the data collection period. Therefore, an extended stretch of work was possible between lunch and the end of the day. Though water was accessible, it was a frequent comment that the employees voluntarily worked through extreme heat. Similar schedules are likely prevalent in other agricultural settings, as well. One study found that a potential barrier to heat illness prevention at work was no access to employer-provided clean drinking water (Fleischer et al. 2013). The National Institute for Occupational Safety and Health (2017) recommends drinking 24–32 ounces of water per hour when working in the heat. Employers need to consider easily accessible water stations in the agriculture industry. Given that agricultural workers frequently work continuously in the field, which is often in remote areas, easily accessible drinking water can minimize barriers to hydration. Future research should explore the extent to which employers understand preparation, fluid loss, and dehydration. Exploring the relationship between workers and employers can inform an experimental design to proactively consider hydration needs. Further research should explore hydration monitoring devices that can be incorporated into industry settings.

The participant group recognized the basic progression of heat-related illnesses and general risk factors. Preliminary symptoms described were headache, cramps, and excessive sweating while providing a general understanding of increased core temperature implications. It was clear the group understood the early onset of heat-related illnesses. However, there seemed to be a gap in participant understanding of more severe heat-related illnesses (e.g., heat stroke) and emergency (e.g., beyond first-aid) situational awareness. When asked about emergency protocols, there was uncertainty about specific actions to be taken. Other research has also shown a lack of understanding of the spectrum of heat-related illnesses and the severity of heat stroke (Hansen et al. 2018). The employees may recognize early warning signs of heat-related illnesses, and potentially even symptoms of severe heat strain, but lack a clear heat stroke understanding, application of immediate treatment measures, and awareness of emergency action plans. As such, the employees would benefit from training on administering heat-related first aid and recognizing the symptoms and severity of heat-related illness (e.g., heat exhaustion or heat stroke) as medical emergencies. This recommendation corresponds with previous literature suggesting robust training with a particular focus on the crucial time between recognizing heat-related illness symptoms and medical treatment (Smith et al. 2021).

The employees discussed frequent non-routine workdays (e.g., weekends), where few staff members would be onsite. Given the critical time sensitivity of receiving heat stroke medical treatment, the lack of training in emergency action plans and in recognizing a heat-related illness emergency is concerning. Agriculture work is frequently remote with work conducted alone. In such situations, employees must be aware of standard protocols for lone workers and emergency response. Likewise, companies relying on coworker transport may be insufficient without appropriate training provided as part of an emergency response plan. Emergencies require employers to provide employees with access to prompt and adequate care (Morrissey et al. 2021). The reliance on coworker transport may not fulfill emergency protocol responsibilities without appropriate training. Therefore, emergency protocols and training should be established and discussed. Future research should explore the effectiveness of emergency action plans (Morrissey et al. 2021), specifically as it relates to heat-related illness. Future research exploring severe heat-related illness understanding and response is warranted for emergency readiness.

### *Topic 2: Perceptions of wearable technology and user-Interface*

During the introduction meeting, the devices were initially believed to be a nuisance. These perceptions were likely due to the unfamiliarity with the wearable devices. Though the perceptions changed regarding the devices, there were several reports of irritation and discomfort for an entire shift. In contrast, device comfort was deemed adequate after the data collection period. However, mentions of continuous adjustments were discussed, especially if participants were excessively sweating. Likewise, the sensor sometimes slipped out of the armband holster and required adjustment. Agriculture workers commonly wear long-sleeved clothing throughout the day. Shedding of overburdened clothing as temperatures increase required device adjustments. This is particularly true for the MākuSafe device, which is worn externally, outside of clothing. The SlateSafety device is worn on the skin surface, so long-sleeved clothing could add nuisance toward placing and removing the device. The tightness and size of the armbands and sensor fixity contributed to the overall device(s) comfort. For instance, the armbands had multiple sizes to fit smaller or larger arms. Outer-layer clothing may have influenced the appropriate armband size. It is important to ensure the armband fits comfortably around the individual's arm. Likewise, observing sensor imprints on the skin may suggest the armband is too tight. Lastly, the MākuSafe sensor slides into an armband holster, requiring a "click" to confirm proper fixity. An important practice is to ensure the devices are secure and comfortable.

The device design and location of the body were discussed. Devices collecting biometric data may require skin contact for efficacy, although it is worth communicating with the manufacturer about thin-layer clothing interferences. For instance, the SlateSafety V2 armband provides heart rate and estimated core body temperature that is worn on the skin (arm). Future research and development can explore whether the devices can be worn over a standard cotton long-sleeve shirt with little interference. Further, manufacturers of devices monitoring the external environment may consider other designs including clothing, belts, or hat clips. Some of these matters emerged as connectivity considerations during pre-job setup. Throughout the data collection period, there were delays during pre-job setup due to poor heart signal and cellular service. Though it was likely that thin clothing interfered with the signal, it was worth discussing the flexibility for the user. The company and manufacturer should converse about error margins regarding flexible wear, connection interferences, and implementation considerations.

The group was interested in device alerting systems. Both devices (MākuSafe and SlateSafety) provide alerting systems through multiple applications. Specifically, the MākuSafe device provides email and Short Message Service (SMS) text alerts when sensor thresholds are exceeded. Sensor thresholds are established by the manufacturer and based on Occupational Safety and Health Administration guidance. Once thresholds are exceeded, a notification will be sent based on the user dashboard setup. The MākuSafe and SlateSafety alerting systems are designed similarly. The administrator updates user information that allows for notification once individuals exceed pre-set thresholds. Individual exposure limit recommendations are based on the American Conference of Governmental Industrial Hygienists heat stress Threshold Limit Values (ACGIH 2017). The SlateSafety V2 vibrates once thresholds are exceeded. The V2 will vibrate four times to indicate exceedance, and twice to indicate return-to-work or recovery thresholds. The participant group emphasized the need to establish an alerting protocol for individual notifications of exceedances. It was discussed that relying on a single-point notification system, such as the device vibration on the user, could easily be missed. For instance, a landscaper using vibrating tools (e.g., weed eater) may not feel the device vibrate. This work task would benefit from a supervisor receiving a text alert in conjunction with device vibrations or vibration continuation requiring user input. This practice would provide layers of protection and offer the ability for immediate action toward risk reduction. Companies looking to adopt wearable technologies should utilize multiple alerting systems and establish safety communication protocols.

The employees made clear their desire to access their exposure data. Throughout the focus group discussion, it was mentioned that many employees want to know their metrics and exposure data. A reported challenge of implementing physiological monitoring devices is that the data must be easily interpreted and actionable by the worker (Morrissey et al. 2021). Employees preferred a visual display of their relevant data. An important consideration is the relevance of the data being collected and provided. Wearable technologies serve different functionalities that benefit occupational health. The employer needs to assess their occupational health needs and applications to appropriately select a device. The device data provided insights into occupational health risks. Real-time monitoring may permit the employer and the worker to review occupational exposures and ensure hazardous conditions are not overlooked. Employers adopting real-time wearable technology should be able to accurately interpret the data and consider data accessibility procedures for the worker.

Minimal privacy concerns were reported during the focus group. These findings oppose previous reports discussing privacy as a critical barrier to wearable technologies (Reid et al. 2017; Schall et al. 2018; Tindale et al. 2022). There was minimal concern related to general oversight while wearing the devices. Though the workers were not concerned with data privacy issues or managerial monitoring, participants commented that they were aware of constant location monitoring during the data collection period.

Only one related qualitative study was identified examining worker needs and preferences related to the use of sensor technologies in workplaces that require physically demanding work (Spook et al. 2019). Of note, this study was conducted outside the U.S., included focus group participants with no prior experience with such devices, and did not include agricultural workers. The focus of this study was on determining what exposures and types of technology workers would be interested in, what would motivate them to use the devices, and what feedback they would like to receive. Participants were interested in wearable sensor technologies that measure occupational heat stress, noise, and fatigue. As with the results of this study, these workers were interested in real-time feedback and access to their own data. However, in contrast to participants in this study, participants in the Spook et al. (2019) study noted concerns over data ownership and privacy.

Several strengths of this study address research gaps. To the authors' knowledge, this is the first study that examined perceived likes, dislikes, and needed improvements in heat stress technologies among agricultural workers. Additionally, this study included practical field use before collecting worker feedback. This allowed the workers to become familiar with and learn the nuisances of the devices.

Also, the investigators tested multiple devices to gain perspectives on diverse heat stress technologies. Lastly, the strength of reflexive thematic analysis encourages subjectivity and creativity in knowledge production, which follows a rigorous methodology for thoughtful engagement and data interpretation (Braun and Clarke 2019; Byrne 2022). This methodology allows researchers to produce knowledge in an organic and flexible analytical process (Braun and Clarke 2019).

## Limitations

This study tested the feasibility of implementing wearable heat stress monitoring technologies in agricultural workers. As such, the investigators did not intervene or fully utilize all device features. For instance, the alert systems were not enabled for the workers to experience. Though the workers had some interaction with device vibrations during setup, they did not experience the full device alerting system. Another limitation is that the study participants were all male. Given the wearable technology nuances, it would be beneficial to receive perceptions from female participants. Further, this study's participants conducted heterogeneous work activities which may limit the extent to which data saturation was achieved. It was determined that data saturation (i.e., no new information or themes emerged from the data) was met in the sample. However, conducting multiple focus groups that include participants performing homogenous job tasks in each group may provide additional verification. This study intended to pilot the qualitative research questions. Therefore, the heterogenous sample was an appropriate population to pilot test. Lastly, the population worked on a research-based agriculture farm. The farm performs cutting-edge research and employs significant use of technology. It is possible the minimal privacy concerns in this sample were due to their familiarity and perspectives from other technological interactions.

## Conclusions

Heat stress and heat strain prevention technologies are emerging as critical controls for the prevention and mitigation of heat-related illness. The use of wearable technologies can provide key metrics to assess risk in real time such that intervention can be immediate. This qualitative feasibility study provides insights into technology implementation and considerations. The participants identified benefits and noted potential barriers to employer implementation in an occupational setting. However, this study can be used as a reference for heat stress wearable technology implementation. These findings provide a foundation for future research opportunities in heat stress mitigation, such as exploring emerging technologies, emergency preparedness, and lone worker use to further improve occupational heat management. These technologies encompass features that can look beyond heat-specific questions and improve safety management systems. This study provides a basis for the implementation of wearable technologies and potential opportunities for continued research.

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## Data availability statement

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research, supporting data are not available.

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