Journal of Agromedicine

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/wagr20

Occurrence of Occupational Injuries and Within Day Changes in Wet Bulb Temperature Among Sugarcane Harvesters

Miranda Dally, Krithika Suresh, Mike Van Dyke, Katherine A. James, Alison K. Bauer, Lyndsay Krisher & Lee S. Newman

To cite this article: Miranda Dally, Krithika Suresh, Mike Van Dyke, Katherine A. James, Alison K. Bauer, Lyndsay Krisher & Lee S. Newman (2023) Occurrence of Occupational Injuries and Within Day Changes in Wet Bulb Temperature Among Sugarcane Harvesters, Journal of Agromedicine, 28:3, 523-531, DOI: 10.1080/1059924X.2023.2169425

To link to this article: https://doi.org/10.1080/1059924X.2023.2169425

JOURNAL OF AGROMEDICINE
2023, VOL. 28, NO. 3, 523–531
https://doi.org/10.1080/1059924X.2023.2169425

Taylor & Francis
Taylor & Francis Group

Check for updates

Occurrence of Occupational Injuries and Within Day Changes in Wet Bulb Temperature Among Sugarcane Harvesters

Miranda Dally[a,b], Krithika Suresh[c], Mike Van Dyke[a,b], Katherine A. James[a,b], Alison K. Bauer[b], Lyndsay Krisher[a,b], and Lee S. Newman[a,b,d,e]

[a]Center for Health, Work & Environment, Colorado School of Public Health, University of Colorado Anschutz Medical Campus, Aurora, CO, USA; [b]Department of Environmental & Occupational Health, Colorado School of Public Health, University of Colorado Anschutz Medical Campus, Aurora, CO, USA; [c]Department of Biostatistics & Informatics, Colorado School of Public Health, University of Colorado Anschutz Medical Campus, Aurora, CO, USA; [d]Department of Epidemiology, Colorado School of Public Health, University of Colorado Anschutz Medical Campus, Aurora, CO, USA; [e]Division of Pulmonary Sciences and Critical Care Medicine, Department of Medicine, School of Medicine, University of Colorado Anschutz Medical Campus, Aurora, CO, USA

ABSTRACT

Objective: Climate change has implications for human health worldwide, with workers in outdoor occupations in low- to middle-income countries shouldering the burden of increasing average temperatures and more frequent extreme heat days. An overlooked aspect of the human health impact is the relationship between heat exposure and increased risk of occupational injury. In this study, we examined the association between occupational injury occurrence and changes in outdoor temperatures through the workday among a cohort of Guatemalan sugarcane harvesters.
Methods: Occupational injuries recorded for the 2014/2015 to 2017/2018 harvest seasons were collected from a large agribusiness employing male sugarcane harvesters in Southwest Guatemala. Wet Bulb Globe Temperature (WBGT) for the same period was collected from the El Balsamo weather station. We used a logistic mixed effects model to examine the association between injury occurrence and (1) the average WBGT during the hour injury was recorded, (2) the average WBGT during the hour prior to the injury being recorded, and (3) the change in the hourly average WBGT prior to the injury being recorded.
Results: There were 155 injuries recorded during the study period. Injuries were recorded most often between 14:00 and 16:00 ($n = 62$, 40%) followed by 8:00 and 10:00 ($n = 56$, 36%). There were significant differences in the average hourly WBGT and the hour in which injuries were recorded (p-value <.001). There were no observable associations between average hourly WBGT (OR: 1.00, 95%CI: 0.94, 1.05; p-value: 0.87), lagged average hourly WBGT (OR: 1.01, 95%CI: 0.97, 1.05; p-value: 0.71), or change in average hourly WBGT (OR: 0.96, 95%CI: 0.89, 1.04; p-value: 0.35) and recorded occupational injury.
Conclusions: This is the first study that has examined how changes in WBGT throughout the day are related to occupational injury among agricultural workers. Although this study did not demonstrate an association, there is a need for future research to examine how various measurements of WBGT exposure are related to occupational injury in agricultural worker populations.

KEYWORDS
Occupational injury; heat exposure; climate change

Introduction

The agricultural industry officially employs nearly 866 million workers worldwide.[1] Crop production is one of the most hazardous sectors within the agricultural industry with an incidence rate of non-fatal occupational injury and illness of 5.2 per 100 workers in the United States.[2] This estimate is likely higher in Central American countries and other low- to middle-income countries (LMIC) where a majority of crop production worldwide occurs.[3] These workers, who perform intense manual labor in hot environments, are expected to be severely impacted by increasing temperatures.[4]

Recent research in the industrialized, temperate climates of Australia,[5] Spain,[6] Canada,[7] Italy,[8] and China[9] shows that as ambient temperature increases the risk of occupational injury increases, regardless of the occupational setting. While comparisons between these studies are difficult due to varying measures of outdoor temperature, the results consistently show that increases in daily average outdoor temperatures increase the risk of occupational injury. In Australia, the risk of occupational injury increased 30% at temperatures above 40.7°C when compared to 25°C.[5] In Canada, occupational injury risk increased 0.2% for each 1°C increase in

CONTACT Miranda Dally Miranda.dally@cuanschutz.edu Center for Health, Work & Environment, Colorado School of Public Health, University of Colorado Anschutz Medical Campus, Aurora, CO, USA

outdoor temperature,[7] whereas in China occupational injury risk increased 1.4% for each 1°C increase in outdoor temperature.[9] We are aware of only a single study that examined the relationship between quantitative measures of occupational heat exposure and recorded injury rate among agricultural workers within an LMIC setting.[10] In that study, we found that injury risk increases 3% for each degree above 30°C, which is significantly higher than estimates from industrialized settings, suggesting current estimates of heat's effect on occupational injury may underestimate the impact on workers in LMIC settings.

While researchers often postulate why there is an increasing occurrence of occupational injuries with increasing heat, current studies are limited in their ability to elucidate such mechanisms given their use of a single summary statistic measurement of heat exposure, often presented as an average or maximum value. Results of a survey of occupational health and safety professionals suggest that fatigue, muscle cramps, and dehydration may be contributory physiological factors that act as precursors to work injuries in hot weather.[11] Outdoor occupational heat exposure is a particular hazard for agricultural workers because it adds to internal heat production during strenuous work.[12] The additive effects of high ambient temperature and increases in metabolic heat production from strenuous work can increase core body temperature with the potential to result in heat illnesses including dehydration, heat edema, heat syncope, heat exhaustion, heat stroke, and death.[13] Increases in core body temperature have also been shown to decrease the ability of workers to perform complex cognitive tasks as well as reduce vigilance.[14] An understanding of the complex relationship between occupational injury and changes in wet bulb globe temperature (WBGT) throughout the day is needed to guide which of these physiological responses to prioritize for injury prevention efforts.

In this study, we examined the association between occupational injury occurrence and changes in outdoor temperatures through the workday among a cohort of Guatemalan sugarcane harvesters during four annual harvest seasons. We hypothesized that higher hourly WBGT would be associated with greater odds of a recorded injury.

Methods

Study population

This analysis used recorded occupational injury data collected on Guatemalan male sugarcane harvesters employed at a single agribusiness in Southwest Guatemala between 2014 and 2018. Workers at this agribusiness consist of those hired from the local communities and migrants from higher altitude communities within Guatemala. Local workers live in their own homes during the harvest and commute to the fields each day, while migrant workers are housed near the mill and are bussed to the fields.[10] Sugarcane harvesters are employed on a six-month basis from November through April each harvest season. Workers are assigned to cutting groups that rotate through numerous fields during the harvest season. The fields are located throughout the Department of Escuintla and are at altitudes ranging from sea-level to 500 m. Typically, sugarcane harvesters are in the field from 7:00 to 17:00 with a company mandated 60-minute lunch break and three mandated 20-minute rest breaks daily. Typically, lunch breaks occur between 12:00 and 13:00 and rest breaks are provided every 90 minutes. A workweek consists of 6 days of consecutive work followed by a rest day.

Manual sugarcane harvesting in Guatemala involves swinging a machete to cut burned fields of sugarcane stalks a few centimeters above ground level, followed by lifting, trimming, and stacking the cane.[15] This work is carried out during the day in full sun at high temperatures and high humidity levels. Manual sugarcane harvesting is considered heavy to very heavy metabolic work with estimates of 6.8 kCal burned per minute.[16] This intensive work contributes to the metabolic heat production of sugarcane workers.

Workers are paid, in part, by how much sugarcane they cut. While workers are paid a minimum salary as required by law, they can earn additional income based on their productivity. Each worker cuts an average of six tons of sugarcane per shift.[15] During the first 2 weeks of the harvest, sugarcane harvesters are provided with an acclimatization period. During this time, they work fewer hours and cut less sugarcane. A full list of occupational safety and health policies and programs currently implemented by the agribusiness have been published elsewhere.[10] Briefly, all workers are provided with access to portable shade, clean, chlorinated water, and electrolytes in the field.[17] The attrition rate during the harvest season is about 25% of workers,[15] which is comparable to other published studies in the agricultural industry in the United States.[18]

Common occupational injuries experienced by sugarcane harvesters include slips, falls, and lacerations. The observed injury rate in Guatemalan sugarcane harvesters at the participating agribusiness was 1.84 per 100 full-time workers annually for the years 2014–2018.[10] Sugarcane harvesters are also at an increased risk of experiencing dehydration. Nurses are stationed in the field with each group of workers to assist with adherence to health and safety recommendations and provide first aid. Physicians circulate among the fields and respond to injuries and illnesses. Workers have access to mill-based medical clinic facilities during and after work shifts. In addition to the monitoring conducted daily by the nurses and physicians, the company undergoes regular audits and supports field-based program evaluations to ensure compliance with occupational health and safety protocols.[17]

Injury measurement

Injury data were collected prospectively by the agribusiness as part of routine business operations. Occupational injuries were self-reported by the worker to their supervisor or the field nurse. Reportable injuries are categorized by the company as falls, struck by a falling object, slips, caught between objects or equipment, strains or sprains, exposure to extreme heat (non-ambient such as steam), exposure to electrical current, exposure to a harmful substance, radiation, or chemical accidents such as dizziness while applying herbicides, being cut specifically by an agricultural tool, vehicular accidents, bites from snakes or insects, other agricultural incidents such as being cut by grass or cactus, or other. Given that it is hypothesized that occupational injury risk increases with increasing ambient temperature due to slippery sweaty hands and decreases in cognitive function, for this analysis we examined only injuries classified as slips, falls, and cuts by an agricultural tool.

Recorded injuries include information on the date of injury, time of injury, cause of injury, type of injury, body part injured, and a written description of the situation surrounding the injury. Potential occupational illnesses resulting from work in hot environments, such as chronic kidney disease or mental health effects, were excluded from the analysis. To reduce information bias, only injuries that were likely to occur during work were included. Therefore, injuries reported outside of the hours of 7:00 to 17:00 were excluded from the analysis.

Injury data had been previously collected by the agribusiness as a routine part of its occupational safety and health program. Data were provided to researchers at the University of Colorado in de-identified form. Institutional review for the evaluation of these data was completed by the Colorado Multiple Institutional Review Board (COMIRB #18–0957). COMIRB determined that informed consent was not required for the evaluation of these de-identified data, since they had been previously collected for business and clinical purposes.

Wet bulb globe temperature

The negative health effects of heat occur because of the body's inability to maintain the core body temperature at the optimal level (37°C/98.6°F).[19] Measuring the risk of increasing core body temperature involves a measurement referred to as heat stress. Heat stress is the combination of external environmental heat with metabolic heat generation. There are over 45 heat stress indices which have been developed[20] from the "six primary components of heat stress – air temperature, mean radiant temperature, absolute humidity, air velocity, and the workers' clothing and activity."[21] Wet bulb globe temperature (WBGT) is one such index measurement commonly used in occupational settings.[22]

For all working days between 2014 and 2018, we obtained data from the El Balsamo weather station (14.28°N, 91.00°W, 280 m above sea level) which were made available free of charge by the Private Institute for Climate Change Research in Guatemala.[23] This weather station lies along the central border of the sugarcane field range, is within approximately 21,600 m of most fields, and is at an altitude of 280 m, the average altitude found for all fields. Weather station data were collected in 15-min increments from the hours of 5:00 to 17:00. The choice to collect data prior to 7:00 allowed us to gather exposure information for those injuries that occurred early at the start of the shift.

Our full method for calculating WBGT is outlined in Dally et al., 2018.[15] Briefly, direct meteorological observations including ambient near-surface air temperature (Ta), relative humidity (RH), incident solar radiation at the surface (S), and wind speed (U) were used to compute the WBGT at 15-min intervals using the equation proposed by OSHA ($WBGT = 0.7Twb + 0.2Tg + 0.1Ta$).[24] Wet bulb temperature (Twb) was estimated from Ta and RH using the empirical equation of Stull, 2011.[25] Globe temperature (Tg) was computed following the physically based formulation of Dimiceli et al.,[26] which requires observed Ta, RH, S, U, and the station coordinates as inputs.

Using methods previously described, estimated WBGT was calculated at each of the 15-min increments. Following best practices for calculating workplace WBGT, adjustments for minimum windspeed were made.[22]

Statistical analysis

Descriptive statistics were computed to summarize the injury count and distribution of WBGT by hour. A chi-square test was used to assess if the proportion of observed injuries differed by the hour of injury. Among those that were injured, a linear mixed-effects model was used to test for differences in the average WBGT by injury time (i.e., hour of day).

Using hour-level data, the primary analysis applied a logistic mixed-effects model to examine the association between injury occurrence and the average WBGT during the hour ($WBGT_{hour}$). To optimize model convergence, the average hourly WBGT was rescaled by subtracting the daily mean WBGT from it. A random effect for date was used to account for clustering of hours within a particular day. In multivariable analyses, time-of-day was adjusted for as a continuous variable and was measured as the hour of the workday when the injury was recorded. Additionally, we tested the hypothesis of whether the effect of WBGT on injury varied by hour of day by including an interaction term between WBGT and time. Similar logistic mixed-effects models were fit to assess the association between two alternate measures of WBGT: (1) average WBGT during the hour prior to injury ($WBGT_{prior}$), and (2) the change in average WBGT from the hour prior to injury to the hour of injury ($WBGT_{change}$). The Akaike information criterion (AIC), a goodness-of-fit measure, was used to compare the model fit between the three WBGT models. Statistical significance was assessed at the 0.05 level. All analyses were performed using R version 4.1.1.[27]

Results

From November 2014 to October 2018, 204 injuries were recorded. Of the 164 slip, fall, or laceration injuries recorded during this time, 155 (76%) were recorded between 7:00 and 17:00 meeting our inclusions criteria. There were 63 injuries meeting the inclusion criteria recorded during the 2014–2015 harvest, 66 injuries recorded during the 2015–2016 harvest, 19 injuries recorded during the 2016–2017 harvest, and 7 injuries recorded during the 2017–2018 harvest.[10] On average, there were 2,734 workers present on any given day during the study period.[10]

Of the 712 working days from November 2014 to October 2018, 131 days had at least one of these types of injuries recorded (18%). There is observed homogeneity in the distribution of temperatures throughout each of the days. In general temperatures decrease from 5:00 to 7:00, prior to the start of the workday. At 7:00 temperatures begin to increase reaching the peak around 12:00 at which time they gradually begin to decrease.

Table 1 presents the distribution of recorded injury and average WBGT at time of injury broken out by hour of the day. There were significant differences in the proportion of injuries recorded at each hour (p-value <.001). Injuries were

Table 1. Distribution of recorded injuries and average WBGT during hour of injury by hour of the day in which the injury was recorded ($N = 155$ injuries).

Hour Injury was Recorded	Number of injuries (%)	Mean WBGT, °C (SD) Mean WBGT, °F (SD)	Min, Max WBGT, °C Min, Max WBGT, °F
7:00	10 (7%)	23.3 (1.7) 73.9 (3.1)	20.5, 25.6 69.0, 78.0
8:00	13 (8%)	29.1 (1.8) 84.4 (3.2)	25.4, 31.9 77.7, 89.4
9:00	21 (14%)	30.5 (1.9) 87.0 (3.5)	27.4, 34.3 81.3, 93.8
10:00	22 (14%)	31.2 (2.0) 88.1 (3.5)	25.8, 34.0 78.5, 93.3
11:00	7 (5%)	33.8 (3.6) 92.8 (6.5)	28.0, 38.7 82.5, 101.7
12:00	3 (2%)	33.2 (1.4) 91.8 (2.6)	31.6, 34.2 88.8, 93.5
13:00	10 (7%)	31.5 (1.8) 88.6 (3.2)	29.3, 34.5 84.8, 94.1
14:00	22 (14%)	30.4 (1.5) 86.7 (2.7)	27.6, 33.4 81.6, 92.1
15:00	19 (12%)	29.8 (1.6) 85.6 (3.0)	26.9, 33.0 80.4, 91.4
16:00	21 (14%)	27.4 (2.0) 81.4 (3.5)	23.2, 31.6 73.8, 88.8
17:00	7 (5%)	27.4 (1.4) 81.3 (2.5)	25.8, 29.6 78.5, 85.4

recorded most often between 14:00 and 16:00 (n = 62, 40%) followed by 8:00 and 10:00 ($n = 56$, 36%). Very few injuries were recorded at 12:00 ($n = 3$, 2%). There were significant differences in the average WBGT by time of injury (i.e., hour of day) (p-value: <0.001).

Association between measures of WBGT and injury

In unadjusted models, we observed no association between the scaled hourly average WBGT and injury occurrence. For each degree, the hourly average WBGT was above the daily mean WBGT the odds of injury in that hour increased 2% (OR: 1.02; 95% CI: 0.96, 1.08; $p = .59$). There was no change in the association between scaled hourly average WBGT and injury occurrence (OR: 1.02; 95%CI: 0.96, 1.08; $p = .61$) after adjusting for hour of the workday. Estimates from the interaction model are provided in Table 2. We detected no interaction effect between hourly average WBGT and hour in which an injury was recorded (p-value: 0.60).

Average hourly WBGT during the hour prior to when injuries were recorded ($WBGT_{prior}$) was not associated with the odds of occupational injury occurrence (OR: 1.01, 95%CI: 0.97, 1.05; p-value: 0.71). The model examining the change in average hourly WBGT between the hour the injury was recorded and the hour prior to the injury ($WBGT_{change}$) was not associated with the odds of occupational injury occurrence (OR: 0.96, 95% CI: 0.89, 1.04; p-value: 0.35). The model examining the change in unscaled average hourly WBGT ($WBGT_{hour}$) estimated that there was no change in the odds of occupational injury occurrence with each degree increase in hourly average WBGT (OR: 1.00, 95%CI: 0.94, 1.05; p-value: 0.87). Model fit statistics, measured by AIC, were similar for all three models. The AICs ranged from 1503.6 to 1504.5, with the model examining hourly change in WBGT having the lowest AIC.

Table 2. Estimates of the association between average hourly WBGT, hour in which injury was recorded, and WBGT and time interaction and the occurrence of occupational injury.

Predictor	Odds Ratio	95% Confidence Interval	p-value
Average hourly WBGT	1.08	0.85–1.39	0.52
Hour injury was recorded	1.00	0.93–1.07	0.90
WBGT by hour interaction	0.99	0.97–1.02	0.60

Discussion

In this study, we demonstrated that injuries were more likely to be recorded during certain parts of the day. Nearly half of the injuries were recorded within 4 hours of the start of the workday, consistent with previous literature.[28,29] Most injuries were recorded near the hottest part of the day, however there was no observed association between hourly measures of WBGT and whether a slip, fall, or laceration was recorded.

Work intensity may contribute to the finding that 40% of the occupational injuries in this study were recorded within the first 4 hours of the work shift. Informal interviews with field supervisors during field data collection for other research and evaluation projects have suggested that work intensity is greater at the beginning of the workday. Supervisors estimate that workers cut approximately four of their six daily tons of cane during the hours of 7:00 to 11:00. It has been observed in a similar workforce in Nicaragua that core body temperature demonstrates a sharp increase within the first hour of work to a level that is then maintained throughout the day.[30] This early work intensity coupled with the resulting physiological responses to the start of work may play a role in injury risk as evidence suggests that changes in core body temperature can impact cognitive function resulting in decreases in reaction time.[31] Future research will be needed to fully test this and other hypotheses. We speculate, for example, that workers may be starting shifts not fully recovered from the previous day's work as indicated by returning to work not fully hydrated.[32]

Most recorded injuries examined in this study were recorded between 14:00 and 17:00. This potentially could be explained by fatigue, resulting in the reduction in a workers' response time over the course of a day. A study examining steel plant worker response times found that workers with the highest heat exposure had the slowest response times, and these slow response times occurred between 14:00 and 15:00.[33] Contradictorily, it was shown that among tree-fruit harvesters psychomotor vigilance task reaction time improved across the work shift, going from an average of 715 ms pre-shift to 611 ms post-shift.[34] A potential explanation for these differing results is the consistency of exertion throughout the day and the role that cumulative work intensity plays. Supervisors note that the second most productive part of the workers' day is between 15:00 and 17:00. This is likely due, at least in part, to workers increasing productivity to meet production targets with the anticipation of the end of the workday. This may suggest that to fully understand how increasing ambient temperatures impact occupational injury occurrence we need to consider the patterns of work intensity and how work intensity covaries with environmental heat exposure.

To our knowledge, this is the first study to examine the association between average hourly WBGT and injury, rather than using a summary statistic of WBGT for the day the injury occurred. While studies have shown a positive link between daily mean WBGT and occupational injury,[5,8,28,29] the use of summary statistics can mask more nuanced relationships between increasing temperatures and occupational injuries. Notably, summary measures of WBGT can introduce misclassification of the exposure. In the present study, 7% of the injuries examined occurred during the first hour of work when the temperature at the time of injury ranged from 21°C to 26°C. The injury that occurred at 21°C was recorded on January 31, 2015, when the daily mean WBGT was 26°C and the daily maximum WBGT was 32°C, resulting in a misclassification of 5°C to 12°C depending on the choice of summary statistic. In this study, we present three more granular ways to assess the relationship between heat and occupational injury. While our results showed no relationship between any of the measures, there is a need to better understand the complex relationship between increasing temperatures and occupational injury risk, including determining which measures of occupational heat exposure are most appropriate to use.

Limitations

This analysis was based on a single agribusiness in Guatemala. While the Association of Sugar Producers of Guatemala (ASAZGUA) has a heat illness prevention protocol that all sugarcane mills are required to comply with, we do not know how the policies and procedures implemented at the company evaluated in this study compare to other sugarcane companies within Guatemala. While there is a strong safety culture present at the agribusiness,[35] underreporting of injuries is a concern.[36] We are unable to assess the generalizability of our findings presented here.

The measured temperatures throughout the workday were homogenous, despite the month in which they were recorded. Additionally, there were only 131 days with recorded injuries. While a non-linear relationship between time and WBGT was demonstrated, models that treated time as categorical were unstable. This limited us to using a linear assumption about the relationship between WBGT and occupational injury risk. Future studies should leverage data from worksites in climates that are more heterogeneous than those of Southwestern Guatemala.

There were multiple sources of potential misclassification. Due to the low event rate, the regression models were left unadjusted for potentially important covariates. This is important as the causes of occupational injuries are multifactorial. Additionally, time of injury was based on when the worker reported the injury which may not be representative of when the injury occurred. For example, because of how the data were structured, the five injuries recorded at 17:00 did not necessarily occur at 17:00 but were rather likely reported at the end of the work shift indicating that they occurred earlier in the day.

Exposure misclassification was also possible. We relied on a single weather station that is in proximity to most of the fields that were actively being harvested. However, because WBGT is a composite measurement, changes in any of the four variables used in WBGT estimation could impact the true WBGT that a worker was exposed to throughout the day. Additionally, WBGT is a measure of exposure rather than response. To understand the physiological response to conducting work in hot environments, there is a need to better characterize patterns of physical exertion, such as through measures of core body temperature and heart rate. To better understand the potential misclassification of WBGT, we are currently conducting a study in which we will compare WBGT measurements between weather station, field monitor, personally worn monitors, and core body temperature monitors.

Conclusions

This is the first study that has examined how changes in WBGT throughout the day are related to occupational injury among agricultural workers. Although this study did not demonstrate an association between more granular measures of WBGT and occupational injury occurrence, it did demonstrate a relationship between time of day and injury, with injuries in this worker population most likely occurring at the beginning and end of the shift. Further studies examining within day changes of temperature and occupational injury risk that can leverage more heterogenous measurements of temperature, capture measurements of physical exertion, and provide more certainty around the timing of injury are warranted.

Disclosure statement

The University of Colorado and Pantaleon have a Memorandum of Understanding. Pantaleon provided the University of Colorado investigators with de-identified data, all of which were collected by the company for business purposes prior to the analysis. The funder had no role in data analysis or data interpretation. The University of Colorado employed appropriate research methods in keeping with academic freedom, based conclusions on critical analysis of the evidence, and reported findings fully and objectively. The terms of this arrangement were reviewed and approved by the University of Colorado in accordance with its conflict of interest policies.

Funding

Work was supported by Training Grant T42 OH00929 funded by the Centers for Disease Control and Prevention. Its contents are solely the responsibility of the authors and do not necessarily represent the official views of the Centers for Disease Control and Prevention or the Department of Health and Human Services.

ORCID

Lee S. Newman http://orcid.org/0000-0002-8067-1159

References

1. Global Agriculture. Industrial agriculture and small-scale farming. 2018. https://www.globalagriculture.org/report-topics/industrial-agriculture-and-small-scale-farming.html. Accessed September, 2019.
2. Bureau of Labor Statistics. Industry injury and illness data. 2017. https://www.bls.gov/iif/oshsum.htm#17Summary_Tables. Accessed September, 2019.
3. International Labour Organization. Statistics and databases. https://www.ilo.org/global/statistics-and-databases/lang–en/index.htm. Accessed October 21, 2019.
4. Schulte PA, Bhattacharya A, Butler CR, et al. Advancing the framework for considering the effects of climate change on worker safety and health. *J Occup Environ Hyg*. 2016;13(11):847–865. doi:10.1080/15459624.2016.1179388.
5. Varghese BM, Barnett AG, Hansen AL, et al. The effects of ambient temperatures on the risk of work-related injuries and illnesses: evidence from adelaide, Australia 2003–2013. *Environ Res*. 2019;170:101–109.
6. Martinez-Solanas E, Lopez-Ruiz M, Wellenius GA, et al. Evaluation of the impact of ambient temperatures on occupational injuries in Spain. *Environ Health Perspect*. 2018;126(6):067002.
7. Adam-Poupart A, Smargiassi A, Busque MA, et al. Effect of summer outdoor temperatures on work-related injuries in Quebec (Canada). *Occup Environ Med*. 2015;72(5):338–345.
8. Riccò M. Air temperature exposure and agricultural occupational injuries in the autonomous province of trento (2000–2013, North-Eastern Italy). *Int J Occup Med Environ Health*. 2018;31:317–331.
9. Sheng R, Li C, Wang Q, et al. Does hot weather affect work-related injury? A case-crossover study in Guangzhou, China. *Int J Hyg Environ Health*. 2018;221(3):423–428.
10. Dally M, Butler-Dawson J, Sorensen CJ, et al. Wet bulb globe temperature and recorded occupational injury rates among sugarcane harvesters in Southwest Guatemala. *Int J Environ Res Public Health*. 2020;17(21):8195.
11. Varghese BM, Hansen AL, Williams S, et al. Determinants of heat-related injuries in Australian workplaces: perceptions of health and safety professionals. *Sci Total Environ*. 2020;718:137138.
12. Kjellstrom T, Holmer I, Lemke B. Workplace heat stress, health and productivity - an increasing challenge for low and middle-income countries during climate change. *Glob Health Action*. 2009;2. doi:10.3402/gha.v3402i3400.2047.
13. Marx J, Rosen P. *Rosen's Emergency Medicine: Concepts and Clinical Practices*. 8th ed. Philadelphia, PA: Elsevier/Saunders; 2014.
14. Hancock PA, Vasmatzidis I. Effects of heat stress on cognitive performance: the current state of knowledge. *Int J Hyperthermia*. 2003;19:355–372.
15. Dally M, Butler-Dawson J, Krisher L, et al. The impact of heat and impaired kidney function on productivity of guatemalan sugarcane workers. *PLoS One*. 2018;13(10):e0205181-e0205181.
16. Crowe J, Wesseling C, Solano BR, et al. Heat exposure in sugarcane harvesters in costa rica. *Am J Ind Med*. 2013;56(10):1157–1164.
17. Krisher L, Butler-Dawson J, Yoder H, et al. Electrolyte beverage intake to promote hydration and maintain kidney function in guatemalan sugarcane workers laboring in hot conditions. *J Occup Environ Med*. 2020;62(12):e696–703.
18. Nantel S. Farm employment in Wisconsin. https://farms.extension.wisc.edu/articles/farm-employment-in-wisconsin/. Accessed May 9, 2022.
19. Spector JT, Masuda YJ, Wolff NH, Calkins M, Seixas N. Heat exposure and occupational injuries: review of the literature and implications. *Curr Environ Health Rep*. 2019;6:286–296.
20. Zare S, Shirvan HE, Hemmatjo R, et al. A comparison of the correlation between heat stress indices (UTCI, WBGT, WBDT, TSI) and physiological parameters of workers in Iran. *Weather Clim Extremes*. 2019;26:100213.
21. Budd GM. How should we measure occupational heat stress? *Temperature (Austin)*. 2016;3(3):369–370. doi:10.1080/23328940.2016.1218992.
22. Lemke B, Kjellstrom T. Calculating workplace WBGT from meteorological data: a tool for climate change assessment. *Ind Health*. 2012;50(4):267–278. doi:10.2486/indhealth.MS1352.
23. ICC Meteorological Information System. https://redmet.icc.org.gt/. Accessed September, 2019.
24. Occupational Safety and Health Administration (OSHA). *OSHA Technical Manual, TED 01-00-015 [TED 1–0.15A]*. Washington, D.C; 2008.
25. Stull R. Wet-bulb temperature from relative humidity and air temperature. *J Appl Meteorol Climatol*. 2011;50(11):2267–2269. doi:10.1175/JAMC-D-11-0143.1.
26 . Dimiceli VE, Piltz SF, Amburn SA. Estimation of black globe temperature for calculation of the wet bulb globe temperature index. *Proc World Cong Engg Comput Sci*. 2011;II:591-299.
27. R Foundation for Statistical Computing. *R: A Language and Environment for Statistical Computing [Computer Program]*. Vienna, Austria: R Foundation for Statistical Computing; 2017.
28. Calkins MM, Bonauto D, Hajat A, et al. A case-crossover study of heat exposure and injury risk among outdoor construction workers in Washington state. *Scandinavian J Work, Environ Health*. 2019;45(6):588–599.
29. Spector JT, Bonauto DK, Sheppard L, et al. A case-crossover study of heat exposure and injury risk

in outdoor agricultural workers. *PLoS One*. 2016;11(10):e0164498-e0164498.
30. Glaser J, Wegman D. Adelante initiative: design & implementation. [Webinar]. 2020. https://www.youtube.com/watch?v=dxHUo0z2mCY.
31. Hancock PA, Vasmatzidis I. Human occupational and performance limits under stress: the thermal environment as a prototypical example. *Ergonom*. 1998;41(8):1169–1191. doi:10.1080/001401398186469.
32. Dally M, Sorensen CJ, Butler-Dawson J, et al. Sugarcane workweek study: mechanisms underlying daily changes in creatinine. *Kidney Int Rep*. 2021;6(12):3083–3086.
33. Chen ML, Chen CJ, Yeh WY, Huang JW, Mao IF. Heat stress evaluation and worker fatigue in a steel plant. *AIHA J (Fairfax, Va)*. 2003;64:352–359.
34. Spector JT, Krenz J, Calkins M, et al. Associations between heat exposure, vigilance, and balance performance in summer tree fruit harvesters. *Appl Ergon*. 2018;67:1–8.
35. Jaramillo D, Krisher L, Schwatka NV, et al. International total worker health: applicability to agribusiness in Latin America. *Int J Environ Res Public Health*. 2021;18(5):2252.
36. Salinas-Tovar JS, López-Rojas P, Soto-Navarro MO, Caudillo-Araujo DE, Sánchez-Román FR, Borja-Aburto VH. El subregistro potencial de accidentes de trabajo en el instituto Mexicano del seguro social. *Salud Pública de México*. 2004;46(3):204–209. doi:10.1590/S0036-36342004000300009.