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Heat exposure and productivity in orchards: Implications for climate change research

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ABSTRACT

Recent studies suggest that heat exposure degrades work productivity, but such studies have not considered individual- and workplace-level factors. Forty-six tree-fruit harvesters (98% Latino/a) from 6 orchards participated in a cross-sectional study in central/eastern Washington in 2015. The association between maximum measured work-shift wet-bulb globe temperature (WBGT_{max}) and productivity (total weight of fruit bins collected per time worked) was estimated using linear mixed-effects models, adjusting for relevant confounders. The mean (standard deviation) WBGT_{max} was 27.9°C (3.6°C) in August and 21.2°C (2.0°C) in September. There was a trend of decreasing productivity with increasing WBGT_{max}, but this association was not statistically significant. When individual- and workplace-level factors were included in the model, the association approached the null. Not considering individual, work, and economic factors that affect rest and recovery in projections of the effects of climate change could result in overestimates of reductions in future productivity and underestimate risk of heat illness.

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Climate change; heat exposure; heat stress; heat-related illness; productivity

Heat-related illness (HRI) is an important public health problem for workers exposed to heat sources indoor and out. United States Bureau of Labor Statistics data indicate that 359 occupational heat-related deaths occurred between the years of 2000 and 2010, and agricultural workers had the highest heat-related mortality rate (3.1 per million worker-years).¹ In addition, several studies reported associations between heat exposure and productivity.^{2–4} The effect of heat exposure on productivity not only has economic implications⁵ but may also be considered by employers when deciding whether to prioritize workplace heat-stress controls.

Although several studies in India reported decreases in productivity with increases in heat exposure,^{2–4} these studies did not consider individual and work-related factors that may be associated with heat exposure and productivity, such as individual work experience and payment schemes. Studies projecting dramatic reductions in productivity in future years due to climate change assumed worksites adhere to existing occupational health guidelines for reducing the amount of time laboring at higher heat exposures.^{6–8}

We sought to estimate associations between heat exposure and productivity in a cross-sectional sample of 46 tree-fruit harvesters in central/eastern Washington during the 2015 harvest season, considering potential individual and work-related confounders. This population of workers is already exposed to heat stress during a typical harvest season, and heat exposure is expected to increase over the next century according to climate model projections.⁹

Methods

Study sites and population

A convenience sample of orchards and adult (age 18 or older) piece-rate (paid by the amount of fruit harvested) tree-fruit harvesters from central/eastern Washington were recruited through University of Washington (UW) Pacific Northwest Agricultural Safety and Health Center contacts in 2015. Forty-six harvesters (34 during August pear harvest and 12 during September apple harvest) from 6 orchards (5 pear orchards and 1 apple orchard) participated for 1 work shift each. Study procedures were

reviewed and approved by the UW Institutional Review Board, and participants provided informed consent prior to participation.

Individual and work-related factors

Individual factors were assessed using an audio computer-assisted self-interview survey instrument on tablet computers.¹⁰ Height and weight were measured to calculate body mass index (BMI [kg/m²]).¹¹ Individual clothing, work and break timing, productivity (number of bins of fruit harvested), and price paid per bin were assessed using field observations.

Heat stress and heat strain

Wet-bulb globe temperatures (WBGTs) were measured using a hand-held WBGT monitor (Extech HT30 WBGT Meter, Extech Instruments; Nashua, NH) near individual workers approximately every 1 to 3 hours. Workers' core body temperatures and heart rates were continuously monitored using CorTemp wireless ingestible sensors (HQ Inc; Palmetto, FL) and Polar chest band monitors (Polar Inc; Lake Success, NY), respectively. Heat stress and strain were assessed for each worker using methods adapted from American Conference of Governmental Industrial Hygienist (ACGIH) guidelines.¹² All workers were categorized on the basis of field observations as performing moderate metabolic rate (300 Watt) work activities with 75%–100% allocation of work in a work/recovery cycle.

Statistical analysis

The association of daily maximum measured WBGT (WBGT_{max}) with productivity (mean kg/hour) was modeled using linear mixed-effects models with intercept random effects for worksites, using the Kenward-Rogers method for small samples.^{13,14} We considered a number of potential confounders, hypothesized to be related to both heat exposure and productivity, coded as follows: work experience (< 1 [reference category], 1–2, 3–5, 6–9, > 9 years), gender (male [reference category], female), price paid per bin (\$15/bin [reference category], \$19/bin, and ≥ \$21/bin), BMI, and shift duration. Clothing was not included in models because of a lack of substantial variability among workers in type of clothing worn; age was not included because it was highly related to years of work experience. Analyses were conducted using R 3.2.5 (R Foundation, Vienna, Austria).¹⁵

Results

Characteristics of the study population are shown in Table 1. The mean (standard deviation) WBGT_{max} during participants' work shifts was 27.9°C (3.6°C) in August (range: 22.0°C–33.1°C) and 21.2°C (2.0°C) in September (range: 19.0°C–22.9°C). Twenty-five workers (74%) exceeded the ACGIH heat stress action limit (AL) (WBGT 25°C) and 15 (44%) exceeded the threshold limit value (TLV) (WBGT 28°C) in August. No workers exceeded the ACGIH AL or TLV in September. Fifty-four percent of those exceeding the AL exceeded the maximum recommended heart rate (sustained heart rate for several minutes above 180 beats per minute minus the age of the worker) or core temperature (38.5°C) for acclimatized workers, per ACGIH guidelines,¹² indicating heat strain. The mean (standard deviation) time-weighted average WBGT was 22.3°C (2.5°C) in August and 15.9°C (1.0°C) in September.

Estimates of the association between WBGT_{max} and productivity are shown in Table 2. There was a trend of decreases in productivity with increases in WBGT_{max} in the unadjusted model (−4.8 kg/hr change in productivity for every 1 degree Celsius increase in WBGT_{max}; 95% CI [−16.3, 6.6]), but this effect approached the null after adjustment for potential confounders (−0.7, 95% CI [−19.8, 18.4]). Sensitivity analyses that included only August pear harvesters and only males yielded similar inferences.

Comment

Our finding of a trend of decreased productivity with increased WBGT_{max} in an unadjusted model, although

Table 1. Characteristics of study population (*n* = 46).

Characteristic	Percentage	Mean	SD
Male	84.8		
Latino/a*	98.0		
Born in Mexico/Central America*	96.0		
Age*		39.1	14.1
Body mass index (kg/m ²)		27.9	4.2
Daily hours worked		6.8	1.5
Reported heat-related symptoms* [†]	52.2		
Years of work experience*			
< 1	10.9		
1–2	6.5		
3–5	8.7		
6–9	8.7		
> 9	65.2		
Price paid per bin			
\$15	26		
\$19	41		
≥ \$21	33		
Total kilograms harvested per hour worked		340.7	84.2

Note. *Self-reported responses.

[†]Self-reported symptoms of dizziness/light-headedness or heavy sweating in the previous week.

Table 2. Effect estimates and 95% confidence intervals from linear mixed-effect models of productivity with random intercept for worksite.

Characteristic	Unadjusted effect estimate	95% CI	Adjusted effect estimate	95% CI
Max measured work-shift wet bulb globe temperature	−4.8	[−16.3, 6.6]	−0.7	[−19.8, 18.4]
Female (ref. male)	—	—	−22.7	[−106.2, 60.8]
Experience (ref. < 1 year)				
1–2 years	—	—	22.9	[−109.1, 155.0]
3–5 years	—	—	104.7	[−42.1, 251.5]
6–9 years	—	—	92.0	[−21.3, 205.3]
> 9 years	—	—	54.6	[−29.0, 138.1]
Body mass index (kg/m ²)	—	—	−4.6	[−11.0, 1.8]
Price per bin (ref. \$15)				
\$19	—	—	−37.0	[−488.6, 414.6]
\$21 or \$25	—	—	−67.9	[−373.9, 238.0]
Shift duration	—	—	−1.1	[−27.0, 24.8]

Note. *Adjusted for all variables in table.

not statistically significant, is consistent with previous studies.^{2,3,5} However, after adjustment for confounders, the association approached the null. Analyses including individual and work-related characteristics provided nuanced implications for possible changes in worker productivity associated with a changing climate.

An often-cited study by Sahu et al² reported a negative association between productivity and WBGT in rice harvesters in India and serves as seminal work demonstrating potential effects of climate change on productivity. Heat exposures were substantially higher than in our study, and Indian workers were able to pace themselves. Differences in acclimatization and cultural and socioeconomic factors such as hydration practices and access to good nutrition and clean water may have also influenced productivity and contributed to differences in findings between Indian workers and our primarily Latino study population.^{2,16} Workers in our study were paid by the amount harvested (piece-rate) so were incentivized to harvest quickly. This incentive may counter the human body's natural response to slow down when experiencing heat stress to minimize the amount of heat generated from heavy physical work.¹⁷ Therefore, workers in our study may have been less likely to exhibit reduced productivity in the heat but at greater risk for HRI. This suggests that worker productivity may not decline as much as projected under climate change, but HRI rates could increase depending on incentive schemes.

It is possible that productivity may decrease with increasing price paid per bin because workers may have a personal economic target resulting in a need to fill fewer bins if the price paid per bin is higher. Lower productivity may occur when workers are less experienced and have longer shift durations. Working longer hours to harvest trees with less readily accessible fruit may be less efficient. Projecting climate change effects on productivity under different future socioeconomic conditions is challenging.

It was apparent in orchard workers in our study that rest periods, which normally allow workers to stay below

ACGIH heat stress ALs and TLVs, were often not adequate. Given that worksites do not always adhere to occupational health guidelines presently, our results do not support climate change projections that assume adherence to standards and guidelines in the future.^{7–8} This assumption can introduce a bias that results in an overestimation of the effect of climate change on decreases in worker productivity and an underestimation of the effect of climate change on HRI rates.

Limitations

This study has several limitations. First, several orchard factors that could influence variability in productivity between orchards were not assessed. These include differences in management practices, harvesting practices, tree growth and condition, and terrain. It was difficult to differentiate crop from orchard differences because there was only one participating apple orchard, and apple harvesters participated during the cooler September month. Second, ACGIH heat stress assessment methods are not intended for use at the individual level although individual heat strain assessments are recommended at exposures above the AL. Ambient heat exposure varies within orchards,¹⁸ and job-based assessments do not take into account this microclimate variability. Third, the analysis of the association between WBGT and productivity was limited by a small sample size, with data collected during only one work shift per participant. Future studies should address this question with more statistical power and ideally with repeated measures. Finally, findings from this study in Latino workers in central/eastern Washington may not be generalizable to other settings, climates, and populations.

Conclusion

Overall, our results suggest the need for more nuance when projecting the effects of climate change on worker

productivity. The relationship between heat exposure and productivity in outdoor workers is complex and likely affected by economic factors and work characteristics that drive endogenous heat load. Realistic assumptions and sensitivity analyses regarding work–rest cycles and consideration of factors other than heat that affect productivity are needed. Not considering these factors could lead to overestimates of the effects of climate change on productivity in outdoor workers and, potentially, to underestimates of the incidence of work-related heat illness.

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