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Associations between heat exposure, vigilance, and balance performance in summer tree fruit harvesters

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ABSTRACT

Background: We sought to evaluate potential mediators of the relationship between heat exposure and traumatic injuries in outdoor agricultural workers.
Methods: Linear mixed models were used to estimate associations between maximum work-shift Wet Bulb Globe Temperature ($WBGT_{max}$) and post-shift vigilance (reaction time) and postural sway (total path length) in a cross-sectional sample of 46 Washington State tree fruit harvesters in August–September 2015.
Results: The mean (SD) $WBGT_{max}$ was 27.4 (3.2)°C in August and 21.2 (2.0)°C in September. The mean pre-work-shift participant urine specific gravity indicated minimal dehydration. Twenty-four percent of participants exhibited possible excessive sleepiness. There was no association between $WBGT_{max}$ and post-shift reaction time or total path length.
Conclusions: Heat exposure was not associated with impaired vigilance or balance in this study, in which the overall mean (SD) $WBGT_{max}$ was 25.9 (4.2)°C. However, the study identified opportunities to ensure adequate pre-work-shift hydration and to optimize sleep and work-shift timing in order to reduce occupational injury and heat-related illness risk.

1. Introduction

Agriculture is among the industries with the highest rates of fatal injuries in the United States (US) (US Department of Labor, 2012). The burden of nonfatal injuries in agriculture is also substantial. Central and Eastern Washington State in the US are productive growing regions and large producers of tree fruit (WA Department of Agriculture, 2014). A study of Washington State Fund workers' compensation claims submitted for injuries that occurred in orchards reported that ladder-related claims, including claims for falls from ladders during tree fruit harvest activities, accounted for approximately half of claims involving more than medical treatment between 1996 and 2001 (Hofmann et al., 2006). These claims were also the most expensive, with a mean annual cost of $3.6 million, compared to claims accepted for other causes.

Several epidemiologic studies have reported an association between ambient heat exposure and injuries in agriculture. A study in Adelaide, Australia reported a 0.7% increase in daily agriculture, forestry, and fishing sector workers' compensation injury claims for each increase of 1 °C daily maximum temperature for temperatures between 14.2 °C and 37.7 °C (incidence rate ratio 1.007, 95% confidence interval [CI] 1.001 to 1.013), using data from one weather station (Xiang et al., 2014). A study in Central/Eastern Washington State using workers' compensation outdoor agriculture traumatic injury claims, which included tree fruit injury claims, and modeled

Abbreviations: ACGIH, American Conference of Governmental Industrial Hygienist; AL, Action Limit; BMI, Body Mass Index; CI, Confidence Interval; PNASH, Pacific Northwest Agricultural Safety and Health Center; PVT, Psychomotor Vigilance Task; SD, Standard Deviation; TLV, Threshold Limit Value; TWA, Time-Weighted Average; US, United States; WBGT, Wet Bulb Globe Temperature.

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ambient exposure data reported traumatic injury odds ratios (95% CI) of 1.14 (1.06, 1.22), 1.15 (1.06, 1.25), and 1.10 (1.01, 1.20) for daily maximum Humidex (apparent temperature) of 25–29, 30–33, and ≥34, respectively, compared to < 25, adjusted for self-reported duration of employment (Spector et al., 2016).

Human studies in laboratory settings have examined the relationship between heat exposure, dehydration, and health outcomes potentially associated with injury risk, including sustained concentration, or vigilance. In a study of young men exercising on a treadmill for 40 min at an ambient temperature of approximately 28 °C and 42% relative humidity, exercise-related mild dehydration (mean percent body mass loss 1.6%) without hyperthermia was associated with adverse changes in vigilance (Ganio et al., 2011). In a similar study of women, mild dehydration was associated with reduced Profile of Mood States concentration scores (Armstrong et al., 2012). Decreased concentration could increase the risk of falls or other injuries.

Studies in laboratory settings have also evaluated balance performance in the setting of exercise, dehydration, and heat exposure. DiStefano et al. conducted a laboratory study of young men exercising on a treadmill for 90 min wearing a 20 kg rucksack in temperate (approximately 18 °C and 50% relative humidity) and hot (approximately 34 °C and 45% relative humidity) conditions at varying levels of hydration (Distefano et al., 2013). Balance was assessed by calculating the sway velocity and elliptical sway area from participants' centers of pressure. The authors found a significant increase in sway velocity and elliptical sway area following exercise in the hot condition with a mean body mass loss of 5.7%, compared to after exercise with smaller mean body mass losses of 1.4% and 3.8% in the temperate and hot conditions, respectively. Exercise is hypothesized to affect balance performance through its effects on fatigue, dehydration, inner ear changes, and hyperthermia (Distefano et al., 2013; Zemková and Hamar 2014). Balance impairment has been reported to be associated with falls in elderly individuals (Merlo et al., 2012; Muir et al., 2013; Maranesi et al., 2016).

The primary objective of this cross-sectional study, performed in Central/Eastern Washington State during pear and apple harvest in August and September, was to examine the relationship between ambient heat exposure and: 1) vigilance; and 2) balance performance in outdoor summer tree fruit harvesters. Vigilance was assessed using a mobile psychomotor vigilance task (PVT) to measure reaction time (Kay et al., 2013). Balance was assessed using a portable, low-cost balance board (Clark et al., 2010) to measure participant center of pressure deviations (postural sway) during quiet standing. We hypothesized that increases in maximum daily wet bulb globe temperatures are associated with increases in reaction time and postural sway in Washington outdoor summer tree fruit harvesters, as one potential mechanism of the increased risk of occupational injury observed in warm conditions in epidemiologic studies.

2. Materials and methods

2.1. Methods

2.1.1. Study sites and population

A convenience sample of adult (age 18 or older) tree fruit harvesters from six Central/Eastern Washington orchards (five pear orchards and one apple orchard) was recruited through University of Washington Pacific Northwest Agricultural Safety and Health (PNASH) Center contacts in 2015. The climate in Central/Eastern Washington is warm and dry, compared to the more mild and humid climate in Western Washington (Western Regional Climate Center, 2014). The Washington agricultural worker population includes seasonal and migrant workers, who are largely Spanish speaking (Washington State Employment Security Department, 2015). Potential participants were eligible to participate if they were paid by the amount harvested (piece-rate). Forty-six workers (34 during August pear harvest and 12 during September apple harvest) participated in the study for one work-shift each. Study procedures were reviewed and approved by the University of Washington Institutional Review Board, and participants provided informed consent prior to participation.

2.1.2. Individual and work factors

Demographic characteristics were assessed at the workplace on tablet computers using an audio computer-assisted self-interview survey instrument, which has been assessed for reliability and validity, as previously described (Spector et al., 2015). The survey was administered in Spanish or English, depending on the participant's primary language, and research staff members were available to answer questions in Spanish or English during the course of the survey. The survey was administered either the day before or the same day the worker participated in the field study. The survey asked whether a doctor or other health provider ever told a participant that they had: 1) conditions affecting balance, including stroke or problems with the inner ear and/or 2) sleep problems, including obstructive sleep apnea. Sleep was assessed using a Spanish language adaptation of the Epworth Sleepiness Scale (Hartford Hospital, 2006; Jimenez-Correa et al., 2009) and using a sleep quality question asking about how well participants slept in the past week, with response categories of very good, fairly good, fairly bad, very bad, and I don't know. The Epworth Sleepiness Scale (Johns, 1991) is a widely used scale that measures daytime sleepiness and is used to help diagnose sleep disorders. Epworth Sleepiness Scale scores are interpreted as: unlikely abnormally sleepy (score 0–7), average daytime sleepiness (score 8–9), may be excessively sleepy (score 10–15), and are excessively sleepy (score 16–24). Height and weight were measured the day the worker participated in the field study to calculate body mass index (BMI [kg/m^2]) (Centers for Disease Control and Prevention, 2014).

2.1.3. Heat stress and 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 hour (median [range] duration between measurements: 63 [1, 144] minutes). We focused on maximum measured work-shift WBGT ($WBGT_{max}$), as WBGT tended to increase to the end of the work-shift, when post-shift outcome measures were performed.

Work and break timing were observed by research staff and recorded on standardized data sheets. During work-shifts, which were on average 6.8, standard deviation 1.5, hours long, 83% (38/46) of participants took one break that was an average of about 20 min, generally in the mid-morning, to eat lunch. Otherwise, there were no breaks observed, and workers harvested steadily throughout their shifts except to stop to drink water or other beverages. Using American Conference of Governmental Industrial Hygienist (ACGIH) guidelines (ACGIH, 2015), all workers were determined to be performing moderate metabolic rate (300 Watt) work activities with 75–100% allocation of work in a work/recovery cycle.

We also calculated time-weighted average (TWA) WBGT values. To calculate the TWA WBGT, each WBGT measurement represented the WBGT for the time interval from the time of that reading to the previous reading. The WBGT measurements were weighted by the time interval, and all the weighted measurements in a given day were divided by the total shift duration for each worker to calculate the TWA WBGT for each participant.

To assess heat strain, workers' gastrointestinal temperatures