Relationship between Payment Schemes and Heat-Related Illness in Washington Agricultural Workers

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Abstract

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Aim: Previous studies in various sectors have indicated that piece rate payment is associated with increased rates of occupational injuries, compared to hourly pay. The relationship between payment type and heat-related illness (HRI) has not previously been studied. We aimed to examine the relationship between payment type and HRI in agricultural workers. We hypothesized that workers paid piece rates, compared to hourly workers, have an increased risk of engaging in behaviors that enhance their risk of HRI, and of developing HRI symptoms, and that this effect is more pronounced in hotter and more humid work environments.

Methods: A cross-sectional survey was administered to 100 agricultural workers in south central Washington using an audio computer-assisted self-interview instrument during the summer of 2013. Mean daily maximum heat indices over the week (HI_{max}) preceding each participant's survey were computed from hourly temperature and relative humidity data obtained from nearby Washington State University AgWeatherNet weather stations. Associations between piece rate

pay and workers' self-reported work exertion (hard/very hard versus light/medium), frequency of hydration (less frequently than every 30 min. versus every 30 min. or more frequently), and specific HRI symptoms (heavy sweating and light-headedness versus no specific symptoms), adjusted for potential confounders, were examined using logistic regression.

Key Findings: The maximum HI ranged from 82°F to 93°F (median 85°F). The odds of greater work exertion was higher in piece rate compared to hourly workers (adjusted OR= 4.08; 95% CI: 1.20, 13.80), and the odds of drinking water infrequently was lower in piece rate compared to hourly workers (adjusted OR= 0.31; 95% CI: 0.12, 0.79). The odds of experiencing specific HRI symptoms were higher in piece rate compared to hourly workers (adjusted OR= 3.93; 95% CI: 1.32, 11.67). We did not observe significant effect modification by HI_{max}.

Conclusion: In this cross-sectional study, piece rate workers had a greater risk of self-reported HRI symptoms compared to hourly workers, and this increased risk may have been mediated in part by increased exertion at work. Results should be confirmed in larger, longitudinal studies that better address potential confounding by elements of work task and incorporate objective measures of hydration and heat health effects.

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INTRODUCTION

HRI and its Impact on Agricultural Workers

Exposure to extreme heat is associated with a number of adverse health outcomes, including heat rash, heat cramps, heat syncope, heat exhaustion, heat stroke, and fatality (US Centers for Disease Control and Prevention, 2014). These outcomes, known collectively as heat-related illnesses (HRI), occur when the body's natural physiological efforts to dissipate excess heat are overwhelmed and normal core body temperature is exceeded. Historically, populations considered vulnerable to HRI have included the very young (<4 years), the elderly (>65 years), and the medically compromised (Wisconsin Dept of Health Services, 2014). However, exertional HRI is a significant cause of excess morbidity and mortality in young, healthy workers in a number of occupational settings, including mining (Lutz, Reed, Turner, & Littau, 2014), construction, agriculture, and others (Bonauto, Anderson, Rauser, & Burke, 2007). Workers laboring under hot and humid ambient conditions (and even those in relatively cool environments) can experience exertional HRI—depending on the worker's degree of metabolic output and level of acclimatization (Adam-Poupart et al., 2013; L. L. Jackson & Rosenberg, 2010).

Despite a decline in the incidence of fatalities in the agricultural sector in the past two years, agriculture still had the highest fatal injury rate of any sector in 2012, at 21.2 fatal injuries per 100,000 full-time equivalent (FTE) workers (Bureau of Labor Statistics, 2013). Heat exposure is an important contributor to non-fatal HRI and death in agricultural workers (L. L. Jackson & Rosenberg, 2010). Between 2003 and 2008, the US Agriculture, Forestry, and Fishing sector experienced the highest mean heat fatality rate, at approximately 0.3 deaths/100,000 FTE workers, compared to 0.02 for all industries (Bureau of Labor Statistics, 2010). Between 1995

and 2005, the Washington State Department of Labor & Industries' State Fund accepted 480 HRI claims; 6.9% of those claims occurred in the Agriculture, Forestry, Fishing and Hunting sector, for an HRI claim incidence rate of 5.2 per 100,000 FTE (Bonauto et al., 2007). The risk of HRI in agricultural workers is expected to increase as climate change increases the frequency and intensity of heat waves (Adam-Poupart et al., 2013; Patz, Campbell-Lendrum, Holloway, & Foley, 2005).

Risk Factors for Exertional HRI

The elderly, young, and medically-compromised are at increased risk for classical HRI (Wisconsin Dept of Health Services, 2014). Exertional HRI, however, occurs in those with high metabolic output rates, particularly (but not necessarily (Armstrong, De Luca, & Hubbard, 1990)) when the person is also experiencing hot and humid environmental conditions.

Exertional HRI has mostly been studied in military populations. In a case-control study of military recruits, risk of exertional HRI increased with increased body mass index (BMI), with those at highest risk having BMIs ≥ 22 kg/m^2 (Gardner et al., 1996). Other risk factors that have been identified in military populations include fatigue, infectious disease, and recently increased volume of physical training (Armstrong et al., 1990).

A cross-sectional study of the medical information associated with WA State Workers' Compensation claims for HRI in non-military workers concluded that 22.1% of the claimants may have had medical conditions or medication use as co-factors in their development of HRI. This is likely an underestimation, due to the non-systematic collection of medical information in claimants. The conditions and medications included beta-blockers, hydrochlorothiazide diuretics,

antihistamines, cardiovascular disease, infectious disease, psychiatric conditions, and daily drug or alcohol use or use in the days preceding the claim (Bonauto et al., 2007).

Generally-accepted risk factors for exertional HRI include poor physical fitness and obesity, hydration status, exertion level, air temperature and humidity, and lack of acclimatization (Carter, Banister, & Morrison, 1999 Feb.; Epstein, Moran, Shapiro, Sohar, & Shemer, 1999 Feb.; Gardner et al., 1996; Kark, Burr, Wenger, Gastaldo, & Gardner, 1996 Apr).

Introduction to Piece Rate and its Impact on Occupational Injuries

Agricultural workers are usually paid either an hourly wage or a set rate per unit of work accomplished, known as a piece rate. Unlike hourly or salaried wages, piece rate contracts directly link compensation with current-period performance. Performance-related payment incentivizes the worker to produce more pieces; there is well-established evidence that piece rate pay increases worker productivity (Gielen, Kerkhofs, & van Ours, 2010; Haley, 2003; Lazear, 2000). Besides increased productivity, employers find that another advantage of piece rate pay is that it enables self-motivation, decreasing the need for close supervision (Roka, 2009). Employers generally establish their remuneration scheme based on which tasks workers will be performing and which crops they'll be working with. Repetitive, monotonous tasks (e.g. harvesting) are often compensated with piece rate, whereas tasks that require a higher level of skill or attention to detail (e.g. pruning) are more likely to be completed by hourly workers (Parent, 2002). Given the incentive for speed that piece rates create, employers may not allow workers handling delicate, easily bruised crops to be paid by the piece. Employers strive to set their piece rates at such a level as to attract workers and satisfy minimum wage requirements, while remaining competitive in their markets (Roka, 2009).

Under piece rate payment schemes, workers are rewarded monetarily for working harder and faster and for taking greater risks (Bender, Green, & Heywood, 2012). Previous studies have established that piece rates are associated with increased occupational injury. A literature review published in 2010 found that 27 of 31 relevant, high-quality articles assessing piece rates and their effects on health and safety reported negative effects (Johansson, Rask, & Stenberg, 2010). None of those 31 articles looked specifically at HRI.

Using data collected for the European Working Conditions Survey (a cross-sectional survey that gathers detailed information about individuals' jobs and working environments) in 2000 and 2005, Bender et al. found that piece rate workers were over 5% more likely to suffer at least one occupational injury than hourly workers, despite controlling for demographics and job hazards (e.g. carrying heavy loads, laboring in tiring positions, exposure to noise, extreme temperatures, smoke, etc.). The margin of this risk difference increased further when manual workers and non-manual workers were separated. Manual piece rate workers experienced 6.7% greater incidence of injury than workers without piece rate pay. The effect was strongest in males, but both genders showed statistically significant associations (Bender et al., 2012).

A number of studies on the association between piece rate wages and occupational injury have been conducted in loggers. A study of Swedish loggers (n=442) who switched from piece rates to hourly wages reported that accident frequency was reduced by 29% and the severity index for the injuries that were sustained decreased by 32% (Sundström-Frisk, 1984). A study of logging contractors in British Columbia (n=8) found that piece rates were associated with behavior that increased the probability of injuries, accidents, and fatalities. Qualitative analyses of these contractors suggested that they preferred to accept the (perceived) relatively low individual risk of morbidity and mortality over the economic loss that was nearly guaranteed by working slower

and/or more carefully (Patterson, 2007). Toupin et al. studied brushcutters in Canada (n=38) and found that piece rate workers increase their exertion (as measured by heart rate) when working in less difficult plots to make up for lost productivity in more challenging areas; their physical workload was, on average, twice the recommended maximum value (Toupin, LeBel, Dubeau, Imbeau, & Bouthiller, 2007).

Similar studies have also been conducted in construction workers. Norwegian construction workers (n=50) who had been seriously injured on the job were interviewed while they were in the hospital. Over one-third of the workers reported that stress induced by time pressure contributed to the cause of their injury (Gravseth, Lund, & Wergeland, 2006).

Less attention has been given to the effect of piece rate pay on agricultural workers. A study of Hispanic migrant farm workers (n=837) in California found that the risk of occupational injury was elevated for female piece rate workers (OR 4.9; 95% CI 1.8-12.8). No association was found among males. Thirty-one percent of the injuries were strains and sprains, and twelve percent were lacerations (McCurdy, Samuels, Carroll, Beaumont, & Morrin, 2003).

No known, published studies have investigated the association between piece rate payment and HRI, but anecdotal evidence suggests a link may exist. Discussions with agricultural workers were conducted as part of the implementation of California's heat illness prevention campaign, and workers shared their perceptions on risks from heat. Notes from moderators indicate: "Participants frequently noted that access to water or the ability to take recovery breaks is constrained by piece-rate payment systems" (Riley, Delp, Cornelio, & Jacobs, 2012). Staff at these sessions also noted that some workers were disinclined to drink water during their shifts because they did not wish to take additional restroom breaks that would subtract from their

productivity (Riley et al., 2012). In a report summarizing their study of migrant farmworkers in Georgia, Fleischer et al. hypothesized that piece rate pay might be an obstacle to the implementation/execution of HRI prevention practices, but they did not specifically investigate that question (Fleischer et al., 2013).

Plausible Mechanisms of Action

An important question is the mechanism by which piece rate pay might exert influence over worker morbidity. A number of hypotheses have previously been proposed. These hypotheses can be grouped into two main categories: (1) those that suggest that the effect stems from the characteristics of the types of workers who have piece rate contracts and (2) those that suggest that the effect is due to the mitigating characteristics of the work—and the incentives it creates—itself. The former category suggests that the types of workers that self-sort into piece rate schemes are less risk adverse or perceive themselves to be less prone to injury, and may therefore engage in more risky behaviors and subsequently experience greater incidence of morbidity (Bender et al., 2012). The former category will not be considered here because, while in some industries workers are able to choose whether they'd like to be paid hourly or piece rate wages, in the agricultural sector, the employer usually makes this remuneration decision. This thesis focuses on the relevant theoretical pathways in the second category. Previously hypothesized pathways connecting piece rate pay and generalized occupational injury are outlined in Figure 1.

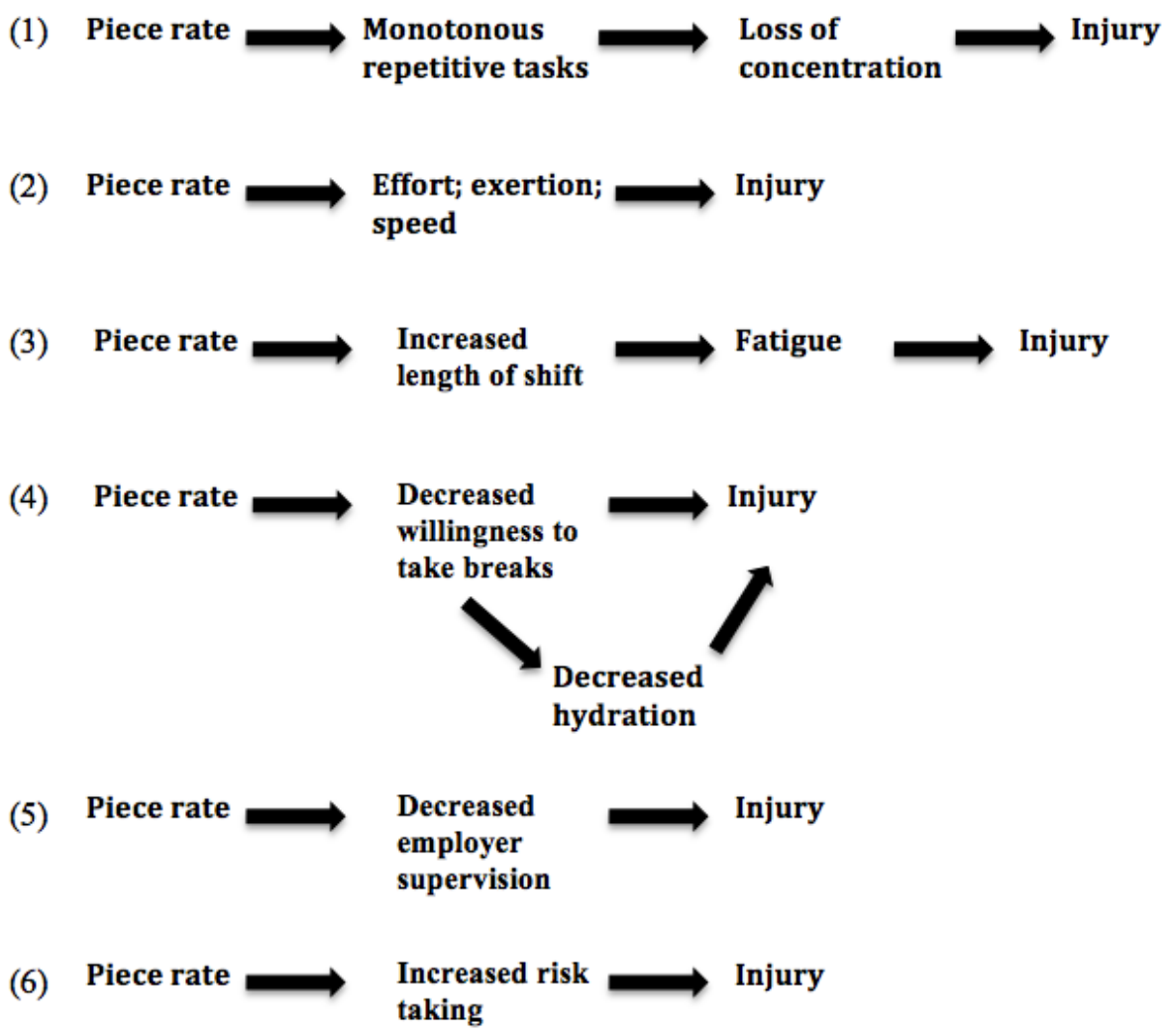

Figure 1. Possible mechanisms by which piece rate pay exerts an effect on occupational injury.

Pathway 1 (Fig. 1) suggests that occupational injuries like strains and sprains may have increased incidence in piece rate workers as a result of lost concentration brought on by the execution of the types of repetitive tasks that employers generally deem amenable to piece rate contracts (Parent, 2002; Wang et al., 2005 Sep). This pathway does not appear to have relevance in the development of HRI, given that lost concentration should not affect the physiological mechanisms leading to HRI.

Pathway 2 (Fig. 1) posits that the economic incentive created by piece rate pay motivates workers to labor harder and faster, putting them at increased risk of accidents (i.e. injury) (Foster & Rosenzweig, 1994; Lilley, Feyer, Kirk, & Gander, 2002 Apr.; Roquelaure et al., 2001 Dec.). This pathway can be adapted to describe HRI as an outcome if exertion, effort, and speed lead to the increased generation of metabolic heat (Fig. 2A).

Pathway 3 (Fig. 1) is derived from theories that piece rate workers are motivated to work longer hours, attempting to maximize financial gain. This may lead to increased incidence of injury due to fatigue (Wright & Quinlan, 2008). This pathway also has potential relevance for the development of HRI, as fatigue may be a risk factor for exertional HRI (Armstrong et al., 1990). This pathway was not considered for this thesis because anecdotal evidence from worksite managers suggested that site supervisors, not workers, mostly determined shift length.

Similarly to Pathway 3, Pathway 4 (Fig. 1) relies on the assumption that piece rate laborers are motivated to work longer than hourly laborers—specifically, this pathway proposes that piece rate workers are less likely to take the breaks that they need to refresh themselves and reduce accident frequency (Lilley et al., 2002 Apr.). It also posits that reducing break frequency and/or length might also reduce the frequency of re-hydration; dehydration is associated with increased risk of falls/accidents (Bates, Gazey, & Cena, 1996). This pathway can be adapted to describe HRI as an outcome if it is assumed that breaks are needed to reduce metabolic heat levels and to keep the worker hydrated (Fig. 2B). Heat transfer and evaporative cooling at the skin's surface are key mechanisms by which the body maintains thermoregulation, but these processes can be overwhelmed with dehydration (L. L. Jackson & Rosenberg, 2010).

Pathway 5 (Fig. 1) notes that piece rate workers are often supervised less closely than their hourly counterparts, due to assumptions that piece rate pay is self-motivating (Roka, 2009). Supervisors theoretically have an interest in reducing workplace injury, and would intervene if they witnessed workers engaging in behaviors that put them at increased risk of injury. This pathway is likely less relevant when HRI is the outcome because the early symptoms of HRI are more mild and may be harder to recognize; therefore, supervisors may not recognize behaviors that put workers at risk unless they've received specialized training.

Pathway 6 (Fig. 1) posits that piece rate contracts encourage workers to behave in ways that generally increase risk of accidents and injuries (Bender et al., 2012; Patterson, 2007). This pathway can be conceptualized as the umbrella pathway by which piece rate pay might be associated with HRI, if the "risky behaviors" are decreased hydration and increased exertion (Fig. 2A & 2B).

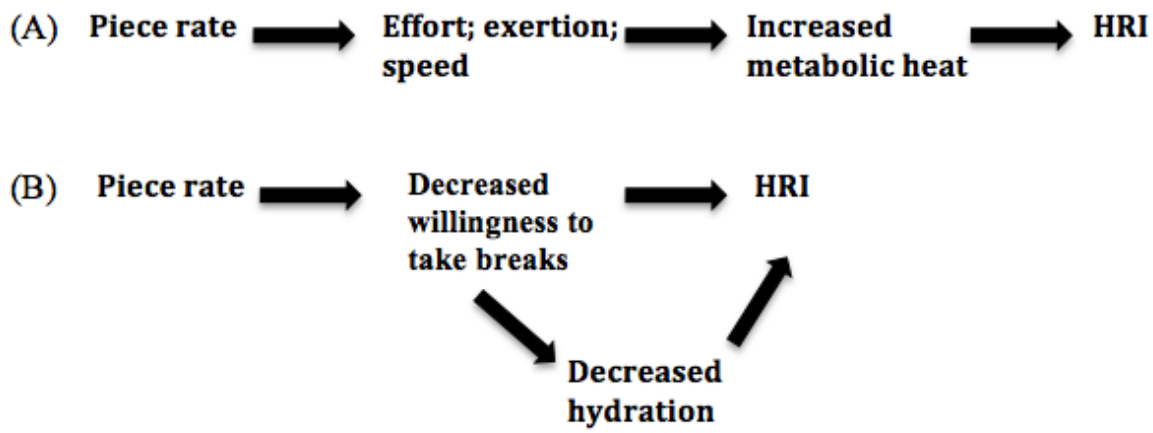

Figure 2. Hypothetical pathways by which piece rate pay may be associated with HRI.

Specific Aims and Hypotheses

The specific objective of this thesis is to investigate payment schemes as potential risk factors for HRI in agricultural workers employed in Washington State. The central hypothesis is that the prevalence of certain risk factors for HRI (i.e. increased exertion and decreased frequency of hydration) and of self-reported HRI symptoms will be greater among workers operating on piece rates than workers being paid an hourly wage.

This research was pursued via the following Specific Aims:

1. To determine the association between payment method and exertion, as a potential risk factor for HRI.
    a. The working hypothesis is that piece rate pay is associated with increased worker exertion compared to hourly pay.
2. To determine the association between payment method and hydration frequency, as a potential risk factor for HRI.
    a. The working hypothesis is that piece rate pay is associated with decreased frequency of worker hydration compared to hourly pay.
3. To assess the association between payment method and self-reported HRI symptoms.
    a. The working hypothesis is that the respondents who work by the piece will report more symptoms of HRI during the time period that they are paid by the piece compared to hourly workers.

To test the hypotheses for all three aims, responses to a cross-sectional survey were evaluated, after relevant assessments of survey question reliability and validity were conducted.

This thesis provides the first known look at HRI risk factors and symptoms that may be associated with piece rate pay in agricultural workers. The results may set the stage for future, larger, longitudinal studies that include objective measures of risk factors for HRI. The findings may help the agricultural community and state agencies take steps to prevent or reduce HRI among outdoor workers.

METHODS

This thesis is a sub-study of a larger pilot study, the aim of which is to more broadly identify risk factors for HRI.

Survey Development

A cross-sectional, tablet-based survey instrument with 64 questions was developed. The questions were designed to identify risk factors for HRI, based on information acquired from focus group discussions with Latino farmworkers (Lam et al., 2013), analysis of workers' compensation claims data (Bonauto et al., 2007), extensive literature review, and other survey instruments. The survey addressed elements of work history; acclimatization, hydration, and cooling practices; HRI symptoms and health; and beliefs about hydration, cooling, clothing, and HRI symptoms and treatment.

Existing, validated questions were utilized where possible, but other questions had to be developed because no Spanish-language versions existed. The survey question measuring perceived exertion was adapted from the validated Borg Rating of Perceived Exertion and OMNI scales (Centers for Disease Control and Prevention, 2011b; Galvin, 2013; Utter et al., 2004). The survey question measuring general health status was obtained from the Behavioral Risk Factor Surveillance System questionnaire (Centers for Disease Control and Prevention, 2013). The survey question asking whether a doctor or health provider has ever told the participant that he/she has any of a number of listed conditions was adapted from the National Health and Nutrition Examination Survey (Centers for Disease Control and Prevention, 2011a).

Some questions asked participants about their "usual" behavior, and others asked participants about their specific behaviors during the "past week." The questions were translated into Spanish

and the survey tool was deployed using Open Data Kit open source software with incorporation of audio and visual elements (Open Data Kit, 2014)

A few months before survey deployment, the draft survey was field tested by six Latino farmworkers who live in central WA year-round and were considered representative of the study population. The testers reviewed the survey on the tablets and provided feedback that was utilized to revise the survey.

Study Sites, Population, and Recruitment

Adults engaging in outdoor, summer agricultural work in eastern or central Washington State were eligible to participate. Participants were recruited following the establishment of a collaborative agreement with the management of their workplaces. Recruitment was carried out by research staff from the University of Washington's Pacific Northwest Agricultural Safety and Health (PNASH) center. Recruitment scripts and consent documents were available in both English and Spanish, and at least one bilingual/bicultural staff person was present for recruitment, enrollment, and data collection. Participants were assured that their employers would not have access to their responses. All participants received a $10 Wal-Mart gift card to account for their time participating in the study.

Survey Deployment

The survey was administered to 100 adult agricultural workers at eight worksites between July and September 2013. The worksites were located in south central Washington State, with most within Yakima County, and one additional site each in Benton and Franklin counties. Most participants took the survey at their worksite, but a handful (n=7) of recruits from the same workplace completed the survey at either the PNASH field research station (n=3) or in their own

homes (a PNASH staff member came to their houses) (n=4). Participants were provided headphones to use while taking the survey.

Survey Reliability and Validity Testing

A subset of twenty participants completed the survey on two separate occasions—once in mid-July and once in early August—and were observed in the field on four different days by research staff, in order to provide data for reliability and validity analyses of the survey. This subset of participants will be referred to as the "observation participants" in this thesis. Research staff noted when observation participants started and stopped work; when and where they took breaks and for how long; what they wore; what beverages they consumed, and in what volumes; strategies they used to cool themselves; and work activities. Observation participants received a $50 gift card for each day they participated in the study, to account for their time.

The observation participants' data were used to conduct survey validation and to evaluate test-retest reliability. Two of the 20 observation participants who participated in July subsequently dropped out of the study, so data from the remaining 18 observation participants were used to test reliability and validity.

Reliability Testing

Survey questions that were considered unlikely to have temporal variation in response were identified for evaluating test-retest reliability. These questions included demographic, work, and certain health characteristics. Observation participants' responses to these questions on July 17, 2013 were compared to their responses a couple of weeks later, on August 1, 2013. The results of the reliability analyses are shown in Table 1. Generally, responses appear to have substantial agreement across surveys.

Table 1. Test-retest reliability for selected variables (N=17) (Krenz & et al., 2014)

Variable	N[a]	% Agreement	Kappa (95% confidence interval[b])	
			Unweighted	Weighted[c]
Work history, training, acclimatization				
Number of seasons worked in orchards	16	63	0.489 (0.167 - 0.797)	0.696 (0.203 - 0.949)
Time of year participant started working for the season	14	79	0.611 (0.220 - 1.000)	0.353 (-0.140 - 1.000)
Training about working outdoors in the heat or health effects of working in the heat in last 12 months	15	73	0.333 (-0.166 - 0.833)	--
Participant gradually increased number of hours of work when they started outdoor work for the season	17	76	0.514 (0.100 - 0.929)	--
Breaks				
Length of afternoon break	15	67	0.250 (-0.136 - 0.696)	-0.013 (-0.280 - 0.519)
Participant feels they are allowed to take extra breaks	16	81	0.455 (-0.063 - 0.972)	--
Hydration				
Distance to drinking water	16	38	0.091 (-0.094 - 0.353)	--
Distance to toilet	15	60	0.286 (-0.039 - 0.683)	-0.034 (-0.586 - 0.519)
HRI symptoms				
Experienced health symptoms or illnesses related to working in the heat[d]	16	94	--	--
Fallen at work because dizzy/faint from the heat	17	94	0.638 (-0.003 - 1.000)	--
Health related questions				
Participant has certain diagnosed health conditions	13	85	0.690 (0.000 - 1.000)	--
Self-reported health status	17	65	0.495 (0.201 - 0.795)	0.794 (0.571 - 0.930)
Frequency of cigarette/tobacco use	17	100	--	--
Demographics				
Year born	17	94	0.937 (0.866 - 1.000)	0.998 (0.992 - 1.000)
Gender	17	100	--	--
Level of education	15	87	0.826 (0.559 - 1.000)	0.970 (0.875 - 1.000)
Weight	16	38	0.344 (0.150 - 0.606)	0.913 (0.678 - 0.985)
Height	16	13	0.089 (-0.028 - 0.257)	0.715 (0.222 - 0.933)
Self-identify as Latino/a	16	100	--	--
Location where born	17	100	--	--
Number of years living in the United States	16	100	--	--
Live in the United States year-round[d]	17	94	--	--

[a]"I don't know" responses were treated as missing values and excluded from the analysis.

[b]Analytical for dichotomous variables, and bias-corrected with 1000 bootstrap replications for categorical variables (Efron & Tibshirani, 1986; Hoffman et al., 2010).

[c]Quadratic weighting (StataCorp, 2013). Not estimated for dichotomous variables or unordered categorical variables.

[d]Kappa coefficients and confidence intervals could not be computed because on one date participants all selected the same response. To compute kappa coefficients, each variable needs to have two or more levels.

Validity Testing

Observations made by field staff were used to validate observation participants' self-reported survey data from early August. Twenty-nine survey questions were selected for validity evaluation, and data pertinent to these questions were extracted from the observational data sheets. Percent agreement was used as the validation measure. The median percent agreement was 82%. Only validity results for the questions pertinent to this thesis are reported here (Table 2). The validity of select survey questions is discussed in more detail beginning on page 62.

Table 2. Results of validity analyses of selected variables. (Krenz & et al., 2014)

Question	N*	Percent agreement
In the past week, what crops have you worked with?	17	70.59
In the past week, what has been your main job task?	17	88.24
This question is asking about your main job task in the past week. How were you paid for your work?	17	94.12
In the past week, at what time of day have you usually started working?	17	94.12
In the past week, at what time of day have you usually stopped working?	17	94.12
How hard has your work been in the past week?	17	29.41
In the past week, how often did you usually drink water at work?	16	31.25
Split into every 30 min or less vs. other	16	56.25
How long does it usually take you to walk to where there is drinking water?	16	100
How long does it usually take you to walk to the toilet?	15	100
What is your weight?	18	97.16
What is your height?	17	96.59
Clothing worn in the past week		
Light colored shirt	17	76.47
Light short sleeve shirt	17	52.94
Light long sleeve shirt	17	58.82
Dark colored shirt	17	52.94
Dark short sleeve shirt	17	64.71
Dark long sleeve shirt	17	70.59
Jacket/coat	17	47.06
Pants	17	23.53

*Field staff were not able to achieve 100% completion of observations, so not all analyses have 18 subjects.

Environmental Data

While data on the environmental conditions were collected for the subset of observation participants, site-specific data were not available for each date of survey collection. Instead, data from Washington State University's AgWeatherNet (AWN) resource were utilized. AWN archives historical weather data collected by a network of 154 automated weather stations (Washington State University, 2014). AWN has stations proximal to all of the study worksites.

The Heat Index (HI) is commonly used in environmental health studies to estimate heat exposure (Anderson, Bell, & Peng, 2013). The HI was developed by Steadman to translate how actual weather conditions would "feel" to a human if the dew point temperature was 14.0°C. In its simplified form, the HI accomplishes this using air temperature and moisture data (Steadman, 1979a). This thesis utilized an equation that approximates the HI using relative humidity as the measure of air moisture:

Equation: $HI = -42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 6.83783*10^{-3}T^2 - 5.481717*10^{-2}R^2 + 1.22874*10^{-3}T^2R + 8.5282*10^{-4}TR^2 - 1.99*10^{-6}T^2R^2$

where T = ambient bulb temperature (°F) and
R = relative humidity (integer percentage) (Rothfusz, 1990)

Data on hourly temperature (°F) and relative humidity (%) were downloaded from AWN to calculate HIs. Preliminary, exploratory analyses confirmed that there was sufficient variability between the temperature and relative humidity data measured by different weather stations on the same day to warrant specifically linking each worksite to the nearest station. For one worksite, two different weather stations were approximately equidistant; the weather station with the more similar elevation was chosen. The distances from the worksites to their respective closest weather stations ranged from 0.70 to 6.87 miles (0.11-11.06 km). The median distance

was 2.07 miles (3.33 km). Since many of the survey questions asked the participants to reflect on the actions, behaviors, and feelings that they had experienced "*in the past week*," the ambient conditions the workers would have experienced during that time frame were used. Based on the worksite and the date where/when the survey was taken, hourly environmental data for the week preceding (and including) the day of the survey was retrieved from the AWN site.

Self-reported shift start/stop times were used to determine proper truncation of the HI data. A survey question asked, "*In the past week, at what time of day have you usually started working?*" Although the majority of participants (n = 86) indicated they had started their shift between 5 and 7 AM, the environmental data was truncated at 4 AM to be inclusive of the nine participants who indicated their shifts had started "*before 5 AM*." The proper truncation for the end of the shift was more important, given that the maximum HI generally occurs in the afternoon. Self-reported shift stop times were considered in the aggregate for participants who shared the same worksite and survey date, and these "cohorts" had their data truncated based on the majority response.

For each hour in a participant's relevant (shift-truncated) "past week" time frame, a HI value was calculated using the temperature and relative humidity values (Equation 1). The maximum HI value for each day was selected, and the daily maximum HIs were averaged over the relevant "past week" time frame to give an average HI_{max} value for each participant, intended to estimate his/her maximum general heat exposure experience for the week upon which he/she was reflecting in the survey. The HI_{max} value was linked to the corresponding participant using their unique participant ID numbers.

Other Measurements

The observation participants also had data on their height, weight, and heart rates collected. The heart rate data were collected at several discrete times over the observed days, using polar chest band heart rate monitors (Polar Electro Inc., Lake Success, NY, USA). Research staff were asked to record heart rates in triplicate, in the morning, afternoon, and at lunch. Research staff were also asked to take notes on participant task and location when heart rate readings were taken.

Analyses

Survey data were downloaded from the tablets to a secure server and then exported to Microsoft Excel spreadsheets for reformatting. Data were then uploaded to Stata; statistical analyses were performed using Stata/IC 11 (StataCorp, College Station, TX, USA).

Although the observation participants took the survey twice, only their first responses (from mid-July) were included in the analysis. It was hypothesized that observation participants might have answered the survey slightly differently on the second viewing; thus, it was considered best to use the first responses to ensure observation participants didn't have a systematic bias relative to other participants, who only took the survey once. Consequently, the two participants who were excluded from the reliability/validity analyses (because they dropped out of the study after the first day) can be used in the larger analysis. One participant was dropped because he or she did not complete the last two-thirds of the survey. Two other participants were dropped because their responses to certain questions indicated that they had not worked in the past week; since the analyses mostly evaluate behaviors that took place over the week preceding the survey, these participants were dropped.

Descriptive Analyses

Univariate and bivariate analyses were conducted on the proposed exposure, outcome, and other variables to explore their distributions. The distributions of covariates across outcome variables and outcome variables and covariates across payment type were examined using 2 x 2 tables. Most data were categorical, but measures of central tendency (e.g. means, standard deviations, and medians) were calculated for the few continuous variables. Initial descriptive findings informed decisions about what forms the various variables should take in the models; follow-up bivariate analyses were conducted after variables were dichotomized. Chi square tests were conducted to assess relationships among select variables.

Inferential Analyses

Following the preliminary descriptive analyses of the survey data, inferential data analyses were conducted, based on *a priori* hypotheses. Logistic regression models were developed to assess the associations between the exposure variable (i.e. payment: hourly vs. piece rate wages) and the outcome variables (i.e. hydration frequency, exertion, and self-reported HRI symptoms). Outcome variables were all dichotomized, with the characteristic expected to be most protective of health coded as the reference category (e.g. frequent hydration, light exertion, and no reported symptoms of HRI). For the exposure variable, hourly workers were coded as 0 and piece rate workers were coded as 1; all reported odds ratios are therefore the odds of the outcome in piece rate workers compared to the odds of the outcome in hourly workers (unless otherwise stated). For all analyses, "*I don't know*" responses were coded as missing and dropped from analyses.

All modeling was conducted in the following order:

1. Unadjusted model (exposure and outcome variable only)

2. Minimally adjusted model (exposure and outcome variable, plus gender and age variables)
3. Fully adjusted model (exposure, outcome, and demographic variables, plus selected confounders or precision variables)
4. Interaction model (fully adjusted model plus an interaction term for the effect of the heat index on the association between payment and the outcome variable)

Aim 1: To determine the association between payment method and potential risk factors for HRI—Exertion Model

Hypothesis: Piece rate workers report having worked harder than hourly workers.

Outcome: The following survey question was utilized to evaluate exertion, "*How hard has your work been in the past week?*" Possible responses were, "*My work was light*," "*My work was medium*," "*My work was hard*," "*My work was very hard*," "*I did not work*," and "*I don't know*." Given that participants may have interpersonal differences in perceptions of task difficulty and that question responses may not be equally spaced with respect to exertion level, responses to this question were dichotomized by grouping participants who reported that their work was "*light*" or "*medium*" as the reference category (0), and by grouping participants who reported that their work was "*hard*" with those who said it was "*very hard.*"

Confounders & Precision Variables: In the fully adjusted model, the association between payment and exertion was adjusted for general health. Participants who indicated that their general health was either "*excellent*" or "*very good*" were coded as the reference category; participants who reported their general health as "*good*" or "*fair*" were coded as 1. General health was considered a precision variable in this model.

Aim 2: To determine the association between payment method and potential risk factors for HRI—Hydration Frequency Model

Hypothesis: Piece rate workers report drinking water less often than hourly workers, possibly due to preferences to limit their breaks to (a) ingest the water, and (b) use the restroom.

Outcome: The following survey question was utilized to evaluate hydration frequency, "*In the past week, how often did you usually drink water at work?*" Possible responses were, "*once every 30 minutes or more often*," "*once every hour*," "*once every hour and a half*," "*once every two hours*," "*once every three hours*," "*once every four hours*," "*I did not drink any water at work*," and "*I don't know*." OSHA recommends drinking water every 15 minutes when working in the heat (Occupational Safety & Health Administration, 2013); given that every 30 minutes was the shortest interval measured by the survey, responses were dichotomized at 30 minutes. Participants who reported drinking "*once every 30 minutes or more often*" were coded as the reference category; participants who reported drinking less frequently were coded as 1.

Confounders & Precision Variables: In the fully adjusted model, the association between payment and hydration frequency was adjusted for exertion, distance to the toilet, and health conditions associated with increased thirst (i.e. diabetes and antihypertensive medication). It was hypothesized that the length of time it took a participant to walk to water or to the toilet might influence hydration frequency, and it seemed appropriate to consider these factors as precision variables. Following validity testing, distance-to-toilet was determined to be the more valid question and was included in the model instead of distance-to-water (page 53). Responses to the distance-to-toilet question were dichotomized at three minutes, with distances less than three minutes as the reference category. The average human walking speed is about 80 meters/minute (Browning, Baker, Herron, & Kram, 2006), so the average human can cover about 240 meters in

three minutes. Though no literature supporting a three-minute cut-off point could be found, it seems reasonable to consider this the maximum distance a worker might think of as "nearby".

Exertion was considered a potential confounder in the association. Exertion and payment method could be related by task; the task a worker is performing influences what payment contract their employer will assign them, and workers (theoretically) experience varying levels of exertion based on what task they are performing. Exertion is also likely related to hydration frequency—the harder one works, the more frequently one needs to re-hydrate (Kenefick & Sawka, 2007). Exertion was coded as a confounder in this model in the same way as it was coded as an outcome variable in the exertion model—"*light*" or "*medium*" difficulty was coded as 0 and "*hard*" or "*very hard*" was coded as 1.

Certain medical conditions and medications are known to impact levels of hydration, and thus might affect how frequently participants drank. One survey question asked, "*In the past week, have you taken pills or medications for any of the following medical conditions, symptoms, or reasons?*" Response options included: high blood pressure; mental health conditions, including depression; diet pills; Parkinson's disease; heart disease; constipation; irritable bowel or bladder; nose congestion, cough, or allergies; seizures; thyroid conditions; and nausea. It was hypothesized that, of these conditions, medications taken for high blood pressure or for dieting could have the most significant effect on hydration (U.S. National Library of Medicine, 2014). No participants reported taking diet pills, but twelve participants reported taking medication for hypertension. Eleven of those twelve also reported drinking at least every 30 minutes. A majority (n = 70) of participants indicated "*No, I have not taken pills or medications for the reasons listed here*." A second survey question asked, "*Has a doctor or other health provider ever told you that you have any of the following conditions?*" Response options included: diabetes; high blood

pressure; heart disease; lung disease, including asthma; overweight or obese; and malaria. It was hypothesized that, of these conditions, diabetes would have the most significant effect on hydration (U.S. National Library of Medicine, 2014). Thirteen participants reported having been told that they have diabetes, and ten of those thirteen reported drinking at least every 30 minutes. A majority (n = 60) of participants indicated "*No, I do not have any of these medical conditions*." A variable was created to describe participants who might have health conditions that make them susceptible to experiencing excessive thirst. Any participant who indicated that they either had diabetes or took medication for high blood pressure was coded as 1; all other participants were coded as the reference category (0). This variable was included as a precision variable.

Aim 3: To assess the association between payment method and self-reported HRI symptoms—Symptoms Models

Hypothesis: Workers paid by the piece have greater odds of reporting symptoms of or associated with HRI than hourly workers.

Outcomes: Two different questions in the survey asked workers to reflect on symptoms of HRI; both were evaluated in this thesis. The question that was used to create the primary symptoms outcome variable was "*In the past week, did you ever experience any of the following symptoms or illnesses during a hot day at work?*" Response options included: skin rash or bumps; painful muscle cramps or spasms; dizziness or light-headedness; fainting; headache; heavy sweating; extreme weakness or fatigue; nausea or vomiting; confusion; and other symptoms or illness. Of these symptoms, "*dizziness or lightheadedness*," "*fainting*," and "*heavy sweating*" were determined to be the most specific symptoms in the physiologic pathway from heat strain to heat illness, and participants reporting these symptoms were coded as 1. The other symptoms, while possible symptoms of HRI, are less specific to HRI and so were coded as the reference category

(along with responses of "*I did not experience any of these symptoms or illnesses*"). The question that was used to create the secondary symptoms outcome variable was "*In the past week, did you ever experience any health symptoms or illnesses that you think may have been related to working in the heat?*" This was a yes/no question. Participants who answered "*no*" were coded as the reference category and participants who selected "*yes*" were coded as 1. The relationship between these two outcome variables is described in Table 3.

Table 3. Relationship between the primary and secondary outcome variables for symptoms of HRI, based on number of participant responses.

		In the past week, did you ever experience dizziness, light-headedness, fainting, or heavy sweating during a hot day at work?		
		No	**Yes**	**Total**
In the past week, did you ever experience any symptoms that you think may have been related to working in the heat?	**No**	60	22	82
	Yes	7	6	13
	Total	67	28	95

Confounders & Precision Variables: The fully adjusted symptoms models included general health, exertion, and hydration frequency as covariates. Exertion was considered as a potential confounder and general health and hydration frequency were considered as precision variables. These covariates were all coded as described above.

Effect Modification by Heat Index

Given that the surveys were collected over the course of a few months, the possibility for significant fluctuations in weather existed. Ambient conditions (i.e. heat index) were considered as potential effect modifiers. The ambient conditions may affect how frequently the workers hydrated themselves, how hard the work felt to them, and whether they experienced symptoms of HRI (L. L. Jackson & Rosenberg, 2010).

The Occupational Safety & Health Administration (OSHA) has developed and published "risk levels" for the heat index, adapted from similar levels listed in the National Oceanic and Atmospheric Administration (NOAA) Heat Index chart. While NOAA's risk levels are intended for the public, OSHA's HI risk levels are specifically for outdoor worksites. OSHA's concept considers HIs less than 91°F to be in the "lower/caution" risk level, HIs 91°F-103°F to be a "moderate" risk, HIs 103°F-115°F to be "high" risk, and HIs greater than 115°F to be "very high to extreme" risk, with appropriate workplace protective measures associated with each risk level (Occupational Safety & Health Administration, 2014).

The HI_{max} values calculated for study participants were compared to the OSHA HI risk levels. All but one participant had HI_{max} values within the "lower/caution" risk level. The one participant who fell outside this category had a measured HI_{max} value of 93.1°F, placing him/her in the "moderate" risk level. HI_{max} values within the "lower/caution" risk level ranged from 82.4°F-90.2°F, with a median HI_{max} value of 85.4°F. A variable was created which dichotomized HI at the median (85.4°F), and this variable was included in the models as an interaction term with payment type, as shown in the equations below.

(Aim 1) Exertion Model: $\text{Logit}(p) = \beta_0 + \beta_1 * \text{pay} + \beta_2 * \text{gender} + \beta_3 * \text{age} + \beta_4 * \text{general health} + \beta_5 * HI_{max} + \beta_6 * HI_{max} * \text{pay}$

(Aim 2) Hydration Frequency Model: $\text{Logit}(p) = \beta_0 + \beta_1 * \text{pay} + \beta_2 * \text{gender} + \beta_3 * \text{age} + \beta_4 * \text{exertion} + \beta_5 * \text{distance to toilet} + \beta_6 * \text{health conditions associated with thirst} + \beta_7 * HI_{max} + \beta_8 * HI_{max} * \text{pay}$

(Aim 3) Symptoms Models: $\text{Logit}(p) = \beta_0 + \beta_1 * \text{pay} + \beta_2 * \text{gender} + \beta_3 * \text{age} + \beta_4 * \text{exertion} + \beta_5 * \text{hydration frequency} + \beta_6 * \text{general health} + \beta_7 * HI_{max} + \beta_8 * HI_{max} * \text{pay}$

Initially, the HI_{max} was going to be considered as a potential confounder in the models, rather than an effect modifier. Since employers make payment scheme decisions based on which task and crop employees will be responsible for during the pay period in question, temporal variation in payment scheme was expected to correlate with the season and, in effect, the heat index. Thus, it seemed plausible that HI_{max} could be independently associated with both payment method and the outcome variables. A descriptive look at the environmental data, however, showed limited seasonal variability in HI_{max} values during the survey period, so it was deemed reasonable to consider HI_{max} as an effect modifier, rather than a confounder, in the logistic regression models.

Secondary Sub-Analyses

A number of sub-analyses were conducted in order to explore *post hoc* hypotheses.

Task Sub-Analyses

To explore the potential effect of task as a confounder, the following descriptive analyses were attempted.

Task sub-analysis 1: Observation participants' survey responses in mid-July and early August were descriptively evaluated to determine if their payment varied in a predictable way as their tasks changed.

Task sub-analysis 2: A sensitivity analysis was performed that evaluated the models only for harvesters (n = 43). To account for minimal statistical power brought about by having only seven hourly harvesters, only the unadjusted and age-, gender-adjusted models were run.

Task sub-analysis 3: In an exploratory analysis, two-, three-, and four-category task variables were created and added to the exertion and primary symptoms models as potential confounders. Since each of the three different task variables produced similar results, the two-category task

variable was chosen for use in the sub-analysis, since it yields slightly better precision. The task variable divides workers into harvesters and "other", with the latter coded as 0.

Task sub-analysis 4: In a mediation analysis, the two-category task variable was added to the exertion model as the main exposure variable, and mediation by payment was explored.

Break Length Sub-Analysis

Afternoon break length was evaluated as an outcome variable in this sub-analysis. There was a need to dichotomize break length so that it could be used as the outcome variable in logistic regression analysis. Since workers are legally entitled to a ten minute break every four hours (WAC 296-131-020), usual reported break lengths of ten minutes or more were coded as the reference category (i.e. 10 minute, 15 minute, and 30 minute long breaks) and 5 minute long breaks and no afternoon breaks were coded as "1". Responses of "*I don't know*" and "*Other amount of time*" were coded as missing. The fully adjusted model included gender, age, and general health as covariates.

Exertion Sub-Analyses

To explore the validity of the exertion question, the following descriptive analyses were attempted.

Exertion sub-analysis 1: Attempts were made to determine whether the level of exertion reported by observation participants correlated with the data collected by their heart rate monitors. These attempts were loosely based on unpublished data by Johnson et al. (of the University of Washington's Ergonomics Program). Johnson et al. compared an objective measure of exertion (heart rate) to a subjective measure (the Borg RPE scale) for various tasks with apples, including green fruit thinning on a ladder, harvesting on a ladder, and harvesting from the ground. The

Borg RPE value, multiplied by 10, approximates heart rate in beats per minute. Their data suggest that the validity of subjective assessments of exertion might vary with task—the margin of difference between the subjective and objective measures was somewhat smaller for green fruit thinning than for harvesting.

The observation participants completed the survey and had their heart rates monitored in both mid-July and early August 2013. According to research staffs' notes, observation participants were thinning apples on the mid-July date and harvesting nectarines on the early August date. Research staff were asked to obtain a baseline heart rate measure from each observation participant, and then to collect measurements in triplicate in the morning, afternoon, and at lunch. They were also asked to note the participants' activity during each measurement; however, due to unforeseen complexities, these directions could not always be followed. There is largely an absence of baseline heart rate data for the observation participants, as well as limited detail in the notes about workers' activities during monitoring. Instead, efforts were made to identify time points when the observation participant may have been at rest, based on general field staff notes. Heart rate data were descriptively assessed to determine if trends could be detected between when observation participants were presumably at rest versus when they were presumably working, and between when they were presumably thinning apples and when they were presumably harvesting nectarines. Self-reported exertion on the two dates was also inspected to see if it correlated with the measured heart rates at all.

Exertion sub-analysis 2: A secondary attempt at verification of the exertion data involved descriptively comparing the observation participants' self-reported tasks/crops and exertion on survey dates 7/17/13 and 8/01/13 to determine whether exertion changed in predictable ways concurrent with changed task.

Exertion sub-analysis 3: Exertion was included in the primary hydration frequency analysis as a confounder, but we recognized that exertion might instead by a mediator of the association between payment and hydration frequency. To assess the exertion covariate as a potential mediator, the fully adjusted hydration frequency model was compared to a model adjusted for all of the same covariates except exertion.

Alcohol Consumption Sub-Analysis

Following assessment of Washington State Fund workers' compensation claims, Bonauto et al. identified alcohol use during the days preceding the claims as a potential contributing factor in the development of HRI (Bonauto et al., 2007). In our survey, participants were asked to report the number of days in the past week that they had at least one drink of any alcoholic beverage, and subsequently, the average number of drinks that they consumed on those days. These responses were utilized to compute the average number of drinks consumed in the past week for each participant. The number of drinks reported ranged from 0 to 21 drinks, with 76% of participants reporting not having had any alcohol in the past week. Based on this exploratory assessment, a four-category variable was created for drinks/week (Table 4). The alcohol variable was added as a covariate in the primary (specific) symptoms model.

Table 4. Reported number of alcoholic drinks consumed in the past week, stratified by gender (n=95).

Drinks per week	% Male (n=50)	% Female (n=45)
0	68	84
1 to 2	12	13
3 to 6	12	0
7 or more	8	2

HRI Training Sub-Analysis

The primary and secondary symptoms models reported associations in the opposite direction from each other. We hypothesized that this unexpected disparity might have arisen because the secondary symptoms model relies on worker knowledge of which symptoms are related to working in the heat. We thought this knowledge would likely be gained primarily through the receipt of HRI training, and we further hypothesized that a worker's likelihood of receiving HRI training increased with their experience in agriculture. A greater percentage of piece rate than hourly workers reported receiving HRI training (Table 5). If piece rate workers are more trained (possibly by virtue of experience), then they might also be more likely to recognize and report symptoms. In our survey, experience was approximated by the question, "*How many seasons have you been working in orchards, vineyards, farms, or in fields?*" For this sub-analysis, we first looked descriptively at the cross-tabulation of experience and HRI training. Then a variable indicating whether or not the participant received HRI training was added to the secondary symptoms model as a potential confounder.

Furthermore, HRI training might influence participants' hydration frequency. Workers who have received training about the importance of hydration in preventing HRI drink more frequently (Brake & Bates, 2003). Therefore, training was also tested as a confounder in the hydration frequency model.

Body Mass Index Sub-Analysis

Being overweight is a risk factor for HRI (Bonauto et al., 2007; L. L. Jackson & Rosenberg, 2010). Following validation of our height/weight measures, BMI was calculated and added to the primary symptoms model, as a precision variable.

RESULTS

Results of Descriptive Analyses

A total of 97 workers completed the survey and were included in analyses. The sample was comprised of roughly half males and half females, with a mean age of 41 years (standard deviation: 12.8 years) (Table 5). The majority of participants were born in Mexico (90.7%) and self-identify as Latino or Latina (99.0%). Most (54%) have not received more than a primary school education. Despite a Washington State requirement that all outdoor agricultural workers receive HRI training (WAC 296-62-09560 (WA State Dept of Labor & Industries, 2009)), 65% of participants reported not having received any such training within the last 12 months.

Table 5 shows the distribution of the variables, stratified by payment type. Hourly and piece rate workers reported similar demographic characteristics, although hourly workers appear less experienced and slightly younger than the piece rate workers. Piece rate workers had a mean (standard deviation) age of 42.3 (13.2) years; hourly workers had 39.1 (12.3) years. Reported tasks performed and crops worked with seem clustered by payment, as expected, given that worksite managers apparently assign payment contracts based on the task and crop to be worked (page 68).

A greater percentage of piece rate workers than hourly workers reported that their work was hard. A greater percentage of piece rate workers than hourly workers reported drinking water at least every 30 minutes. A greater percentage of hourly workers reported experiencing symptoms of HRI when it was phrased as a yes/no question; the reverse is true when workers had to report specific symptoms. The distributions of self-reported general health status and distance to walk to the toilet at work appear equitable across the two payment methods.

Table 5. HRI survey participant characteristics, stratified by payment scheme (N=97)

Survey question	% Hourly (n=49)	% Piece (n=48)	% Total (n=97)
Gender			
Male	51.0	54.2	52.6
Ethnicity			
Latino/a	98.0	100.0	99.0
Other	2.0	0.0	1.0
Age (years)			
18-24	14.3	14.6	14.4
25-34	22.4	16.7	19.6
35-44	26.5	20.8	23.7
45-54	22.4	27.1	24.7
55+	14.3	20.8	17.5
Region of birth			
United States	6.1	8.3	7.2
Mexico	91.8	89.6	90.7
Central America	2.0	2.1	2.1
Highest level of education			
Part/all of primary school	49.0	58.3	53.6
Part/all of middle school	16.3	14.6	15.5
Part/all of high school	22.4	25.0	23.7
Part/all of college or university	2.0	2.1	2.1
I don't know	10.2	0.0	5.2
Have you had HRI training in last 12 months?			
Yes	26.5	39.6	33.0
No	69.4	60.4	65.0
I don't know	4.1	0.0	2.1
Number of seasons worked in orchards, vineyards, farms, or fields			
Less than one	10.2	4.2	7.2
One to two	18.4	4.2	11.3
Three to five	12.2	20.8	16.5
Six to nine	20.4	10.4	15.5
Ten or more	36.7	60.4	48.5
I don't know	2.0	0.0	1.0
Time of year participant started working for the season			
Before May	44.9	52.1	48.5
During first half of May	18.4	12.5	15.5
During last half of May	8.2	10.4	9.3
During first half of June	16.3	14.6	15.5
During last half of June	2.0	6.3	4.1
After June	6.1	4.2	5.2
I don't know	4.1	0.0	2.1
Gradually increased number of hours of work when they started outdoor work for the season?			
Yes	32.7	35.4	34.0
No	65.3	64.6	65.0
I don't know	2.0	0.0	1.0
Crop(s) worked with in week prior to survey*			
Apples	79.6	60.4	70.1
Pears	8.2	29.2	20.6

Table 5. HRI survey participant characteristics, stratified by payment scheme (N=97)

Survey question	% Hourly (n=49)	% Piece (n=48)	% Total (n=97)
Crops continued			
Cherries	14.3	22.9	18.6
Other tree fruit	10.2	10.4	10.3
Hops	4.1	4.2	4.1
Grapes	0.0	4.2	2.1
Blueberries	0.0	8.3	4.1
Other berries	0.0	0.0	0.0
Vegetables	0.0	2.1	1.0
Other crops	6.1	8.3	7.2
I don't know	0.0	2.1	1.0
Task			
Pruning	4.1	4.2	4.1
Thinning blossoms	4.1	4.2	4.1
Thinning green fruit	38.8	0.0	19.6
Weeding	10.2	0.0	5.2
Harvesting crops	14.3	75.0	44.3
Sorting fruits or vegetables	2.0	14.6	8.3
Packing fruits or vegetables	2.0	0.0	1.0
Other jobs	24.5	2.1	13.4
Exertion			
Light/medium	91.7	70.8	81.3
Hard/very hard	8.3	29.2	18.8
Frequency of hydration			
Every 30 min or more	41.7	72.9	57.3
Less often than every 30 min	58.3	27.1	42.7
Experienced symptoms related to working in the heat in the past week			
No	79.2	93.6	86.3
Yes	20.8	6.4	13.7
Experienced dizziness/light-headedness, fainting, or heavy sweating in past week			
No	79.6	58.3	69.1
Yes	20.4	41.7	30.9
Distance to toilet			
≤3 min walk	67.4	63.8	65.6
>3 min walk	32.7	36.2	34.4
Self-reported health status			
Excellent	20.4	14.6	17.5
Very good	8.2	16.7	12.4
Good	42.9	41.7	42.3
Fair	28.6	27.1	27.8
Poor	0.0	0.0	0.0
I don't know	0.0	0.0	0.0
Reported having diabetes and/or taking blood pressure medication			
No	81.6	72.9	77.3
Yes	18.4	27.1	22.7

**Participants could list more than one crop.*

Descriptive comparisons were also conducted for the different worksites themselves (Table 6). The number of participants from each worksite ranged from 2 to 28 workers. A majority of sites have workers reporting being paid under both payment schemes. Harvesting is largely, but not exclusively, paid by the piece. Some participants from workplaces #4 and #7 reported being paid by the piece for harvesting tree fruit and some reported being paid by the hour. For all worksites, the majority of participants reported that their shifts started prior to 7 am, and many reported ending their shifts between 1 and 3 pm. The most commonly reported feature of the worksite that aided in cooling off the participants was trees. The percentage of workers reporting having received HRI training within the last 12 months was highly variable among worksites—ranging from 0-83.3%.

Figure 3 depicts a map of the HI_{max} values measured over the week preceding (and including) the date the survey was completed. Of the thirty participants who completed the survey in mid- to late July, eleven (36.7%) were laboring in HI_{max} conditions above the HI_{max} median value of about 85°F, and 54.5% of those eleven participants reported doing "*other jobs*" and 27.3% reported weeding. Of the 67 participants who completed the survey between the end of August and the very beginning of September, 39 (58.2%) experienced conditions above 85°F, and 56.4% of those 39 participants reported harvesting crops and 15.4% reported sorting crops.

Table 6. Descriptive characteristics of the worksites (n=8)*.

	Workplace ID								
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
N	6	23	4	19	28	3	2	5	7
% Male	83.3	43.5	25	47.4	57.1	33.3	50	60	71.4
Mean age, yrs (Std. Dev.)	53.7 (11.0)	43.3 (11.8)	41.3 (16.1)	33.6 (10.6)	39.8 (13.8)	39.3 (11.0)	49.5 (0.7)	38.8 (15.8)	42.7 (8.8)
Date(s) survey taken (%)	28-Aug (100) - -	2-Sept (65) 3-Sept (35) -	2-Sep (100) - -	17-Jul (100) - -	25-Jul (4) 26-Aug (92) 28-Aug (4)	12-Jul (66) 15-Jul (33) -	28-Aug (100) - -	1-Sep (100) - -	25-Jul (100) - -
% Paid piece	66.7	82.6	0	5.3	71.4	0	50	60	0
Piece tasks (n)	Harvest TF (3) Prune TF (1)	Harvest TF (14) Harvest O (4) Sort TF & O (1)		Harvest TF (1)	Harvest TF (10) Sort TF (6) Thin blossoms (2) Prune hops (1) Other job w/ TF (1)		Harvest TF (1)	Harvest TF (3)	
% Paid hourly	33.3	17.4	100	94.7	28.6	100	50	40	100
Hourly tasks (n)	Sort TF (1) Other job w/ TF (1)	Thin TF (1) Prune TF (1) Other job w/ TF (1) Other job w/ O (1)	Thin O (1) Harvest O (1) Weed O (2)	Thin TF (17) Other job w/ TF (1)	Weed TF (1) Harvest TF (4) Thin TF (1) Other job w/ TF (2)	Thin TF (1) Weed O (1) Other job w/ TF (1)	Pack TF & O (1)	Harvest TF (2)	Prune TF (1) Weed TF (1) Other jobs w/ TF (5)

Table 6. Descriptive characteristics of the worksites (n=8)*.

		Workplace ID								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	Time shifts started (n)	5-7 am (6)	5-7 am (22) 7-9 am (1)	5-7 am (4)	<5 am (3) 5-7 am (15) >10 am (1)	<5 am (3) 5-7 am (25)	<5 am (1) 5-7 am (2)	5-7 am (2)	5-7 am (5)	<5 am (2) 5-7 am (5)
	Time shifts ended (n)	12-1 pm (2) 1-3 pm (4)	<10 am (1) 12-1 pm (3) 1-3 pm (15) 3-5 pm (4)	3-5 pm (2) >5 pm (2)	12-1 pm (1) 1-3 pm (14) 3-5 pm (4)	12-1 pm (11) 1-3 pm (17)	3-5 pm (3)	10-12 (1) 12-1 pm (1)	12-1 pm (2) 1-3 pm (3)	12-1 pm (1) 1-3 pm (5) 3-5 pm (1)
Amenities available at workplace for cooling**	**Shade structure**	x				x		xx	x	
	Trees	xx	xx	xx	xx	xx	xx	xx	xx	xx
	Fans							xx		
	Rest stations	x	x			x		xx	x	
	Building w/ AC							xx		
	Other									
	None		x	x	x		x			x
	% Workers who received HRI training in the last yr.	83.3	43.5	25	15.8	32.1	0	0	60	42.9

*9 discrete workplaces are described here. Workplace ID #2 and #5 represent the same orchard, but workers in #2 completed the survey in their homes and workers in #5 completed it at a research facility.

**'XX' indicates ≥50% of surveyed employees reported this.

TF = Tree fruit; O = other crops

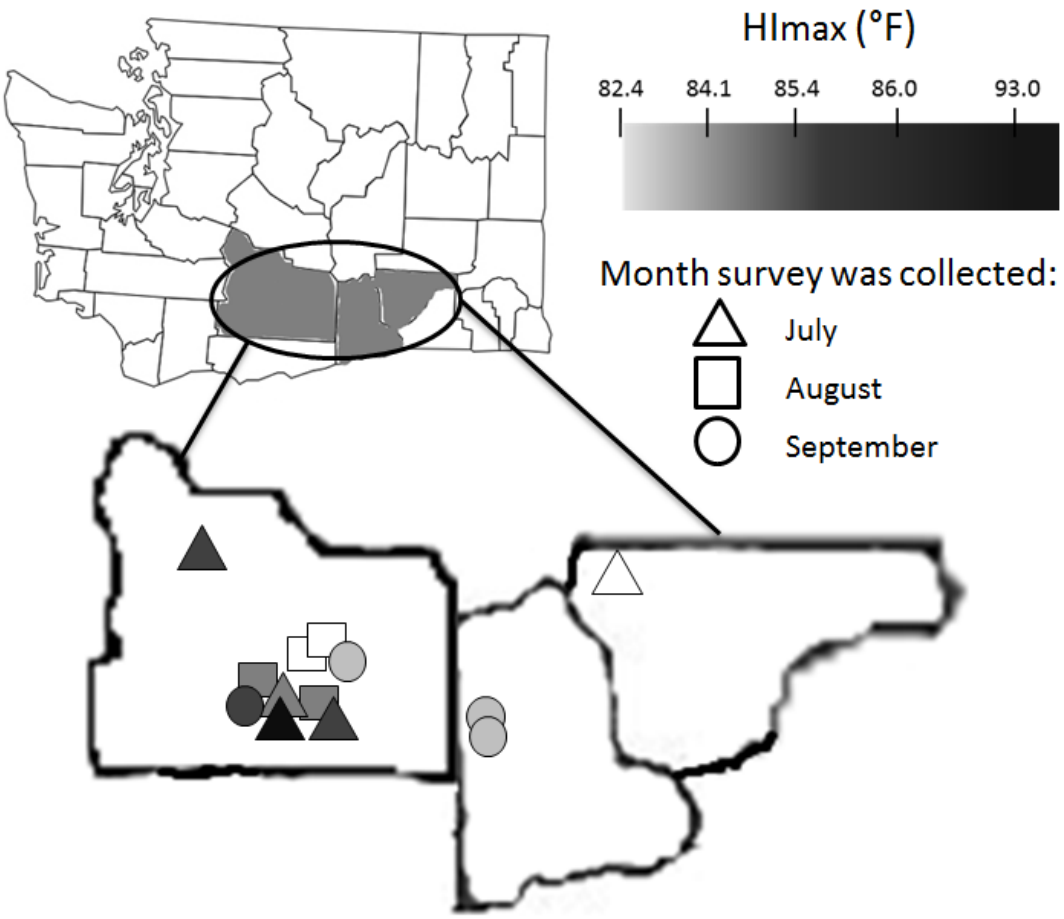

Figure 3. HI_{max} values measured over the week preceding (and including) the date the survey was completed. The HI_{max} values (°F) are mapped over the AgWeatherNet stations in Yakima, Franklin, and Benton counties from which they were obtained. The magnitude of the HI_{max} value is depicted by hue; the date the survey was taken is depicted by shape.

Results of Inferential Analyses

The unadjusted, minimally adjusted, and fully adjusted models are shown in Table 7.

Aim 1: To determine the association between payment method and potential risk factors for HRI—Exertion Model

In the unadjusted model, the odds of greater exertion were higher for piece rate compared to hourly workers (unadjusted OR: 4.53; 95% CI: 1.37, 15.01). In the age- and gender-adjusted model, the odds of reporting greater exertion were higher for piece rate compared to hourly workers (adjusted OR: 4.07; 95% CI: 1.20, 13.76). In the fully adjusted model (adjusted for age, gender, and general health), the odds of greater exertion were higher for piece rate compared to hourly workers (adjusted OR: 4.08; 95% CI: 1.20, 13.80).

Aim 2: To determine the association between payment method and potential risk factors for HRI—Hydration Frequency Model

In the unadjusted model, the odds of drinking water infrequently (i.e. less often than every half hour) were lower in piece rate compared to hourly workers (unadjusted OR: 0.27; 95% CI: 0.11, 0.63). In the age- and gender-adjusted model, the odds of drinking water infrequently were lower in piece rate compared to hourly workers (adjusted OR: 0.28; 95% CI: 0.12, 0.69). In the fully adjusted model (adjusted for age, gender, exertion, the distance to the toilet, and health conditions associated with increased thirst), the odds of drinking water infrequently were lower in piece rate compared to hourly workers (adjusted OR: 0.31; 95% CI: 0.12, 0.79).

Table 7. Odds ratios (95% confidence intervals) of outcomes in piece rate compared to hourly workers, and interaction of payment type with heat index (n=96).

Outcome	Model	OR (95% CI) of association of outcome with payment type (models without payment*heat index interaction)		OR[a] (95% CI) of association when HI is ≤85°F ("low") or >85°F ("high") (models including payment*heat index interaction)	
		OR	95% CI	OR	95% CI
Infrequent Hydration (less than every 30 min vs. ref: every 30 min or more)	Unadjusted	0.27	(0.11, 0.63)	-	-
	Age-, gender-adjusted	0.28	(0.12, 0.69)	-	-
	Fully adjusted[b]	0.31[c]	(0.12, 0.79)	-	-
	Fully adjusted (low HI)	-	-	0.35[c]	(0.09, 1.32)
	Fully adjusted (high HI)	-	-	0.28[c]	(0.08, 1.04)
High Exertion (hard/very hard vs. ref: light/medium)	Unadjusted	4.53	(1.37, 15.01)	-	-
	Age-, gender-adjusted	4.07	(1.20, 13.76)	-	-
	Fully adjusted[d]	4.08	(1.20, 13.80)		
	Fully adjusted (low HI)	-	-	3.63	(0.62, 21.34)
	Fully adjusted (high HI)	-	-	4.49	(0.82, 24.70)
Specific HRI Symptoms (heavy sweating and/or light-headedness vs. ref: none)	Unadjusted	2.71	(1.10, 6.69)	-	-
	Age-, gender-adjusted	3.52	(1.34, 9.28)	-	-
	Fully adjusted[e]	3.93	(1.32, 11.67)	-	-
	Fully adjusted (low HI)	-	-	6.33	(1.32, 30.42)
	Fully adjusted (high HI)	-	-	2.60	(0.65, 10.35)
HRI Symptoms (yes vs. ref: no)	Unadjusted	0.26[c]	(0.07, 1.01)	-	-
	Age-, gender-adjusted	0.27[c]	(0.07, 1.10)	-	-
	Fully adjusted[e]	0.20[f]	(0.04, 0.97)	-	-
	Fully adjusted (low HI)	-	-	0.10[f]	(0.01, 1.15)
	Fully adjusted (high HI)	-	-	0.36[f]	(0.05, 2.60)

[a]The odds ratios represent the association of the outcome with payment type when the heat index is either ≤85°F ("low") or >85°F ("high"). The interaction is tested only in the fully adjusted models, which are adjusted for the covariates described in footnotes b, d, & f, plus the HImax main effect and the interaction term pay * HI. All interaction terms are not statistically significant.

[b]Adjusted for age, gender, exertion, distance to the toilet, and health conditions associated with thirst (i.e. diabetes and antihypertensive medication)

[c]One observation missing

[d]Adjusted for age, gender, and general health

[e]Adjusted for age, gender, exertion, hydration frequency, and general health

[f]Two observations missing

Aim 3: To assess the association between payment method and self-reported HRI symptoms—Symptoms Models

Primary symptoms model

In the unadjusted model, the odds of experiencing specific HRI symptoms were higher in piece rate compared to hourly workers (unadjusted OR: 2.79; 95% CI: 1.13, 6.86). In the age-, gender-adjusted model, the odds of reporting specific HRI symptoms were higher in piece rate compared to hourly workers (adjusted OR: 3.57; 95% CI: 1.36, 9.39). In the fully adjusted model (adjusted for age, gender, general health status, and worker exertion and frequency of hydration), the odds of reporting specific HRI symptoms were higher in piece rate compared to hourly workers (adjusted OR: 3.93; 95% CI: 1.32, 11.67).

Secondary symptoms model

In the unadjusted model, the odds of reporting symptoms were lower in piece rate compared to hourly workers (unadjusted OR: 0.26; 95% CI: 0.07, 1.01). In the age-, gender-adjusted model, the odds reporting symptoms were lower in piece rate compared to hourly workers (adjusted OR: 0.27; 95% CI: 0.07, 1,10). In the fully adjusted model (adjusted for age, gender, general health status, and worker exertion and frequency of hydration constant), the odds of reporting symptoms were lower in piece rate compare to hourly workers (adjusted OR: 0.20; 95% CI: 0.04, 0.97).

Effect Modification by Heat Index

There was no significant effect modification by HI_{max} in any of the models (Table 7). The effect estimates represent the odds ratio for the association of payment and outcome when the heat index was either above 85°F (“high”) or 85°F or below (“low”). The estimates are consistent with those obtained from the models without effect modification.

Secondary Sub-Analyses

Task Sub-Analyses

Task sub-analysis 1: In mid-July, observation participants were mainly thinning apples; in early August, they were mainly harvesting nectarines. The observation participants' reported payment schemes did not change substantially for the two dates; observation participants were paid hourly on both survey dates.

Task sub-analysis 2: Table 8 describes the distribution of covariates among harvesters. Hourly and piece rate harvesters reported similar demographic characteristics.

Table 8. Descriptive characteristics of harvesters (n=43), stratified by payment.

Characteristic	Hourly (n=7)				Piece (n=36)			
	N	%	Mean	SD	N	%	Mean	SD
Male	5	20	--	--	20	80	--	--
Female	2	11.1	--	--	16	88.9	--	--
Age	7	--	41.1	16.8	36	--	42.3	13.7
Hydration Frequency								
Every 30 min	2	7.1	--	--	26	92.9	--	--
Less often	5	33.3	--	--	10	66.7	--	--
Exertion								
Light	7	22.6	--	--	24	77.4	--	--
Hard	0	0	--	--	12	100	--	--
Primary Symptoms								
No specific symptoms	6	27.3	--	--	16	72.7	--	--
Specific symptoms	1	4.8	--	--	20	95.2	--	--
Secondary Symptoms								
No	7	17.9	--	--	32	82.1	--	--
Yes	0	0	--	--	3	100.0	--	--
Distance to toilet								
≤3 min	5	18.5	--	--	22	81.5	--	--
>3 min	2	12.5	--	--	14	87.5	--	--
Health conditions associated w/ thirst								
No	6	18.8	--	--	26	81.25	--	--
Yes	1	9.1	--	--	10	90.9	--	--
General Health								
Very good	1	12.5	--	--	7	87.5	--	--
Fair	6	17.1	--	--	29	82.9	--	--

The survey population was restricted to harvesters only. Only the specific symptoms and hydration frequency models could be run, due to lack of variability in the distribution of the variables for the other models. The hourly harvesters all reported "*light*" work and "*no*" symptoms of HRI. In the age- and gender-adjusted hydration frequency model, the odds of drinking water infrequently were lower in piece rate compared to hourly harvesters (adjusted OR: 0.15; 95% CI: 0.02, 1.01). In the age- and gender-adjusted specific symptoms model, the odds of reporting specific HRI symptoms were higher in piece rate compared to hourly harvesters (adjusted OR: 8.63; 95% CI: 0.88, 85.0).

Task sub-analysis 3: When the two-category task variable was added to the exertion and primary symptoms models as a confounder, the effect estimate decreased and lost significance (Table 9). The odds of a piece rate worker working hard compared to an hourly worker were 3.36 (95% CI: 0.77, 14.61), after adjustment for task, age, gender, and general health. The odds of a piece rate worker reporting specific HRI symptoms compared to an hourly worker were 1.36 (95% CI: 0.34, 5.47), after adjustment for task, age, gender, general health, exertion, and hydration frequency.

Table 9. Odds ratios (95% confidence intervals) of outcomes in piece rate compared to hourly workers, when adjusted for a two-category task variable (harvesters vs. other) (n=96).

Outcome	Model	OR (95% confidence interval) of association of outcome with payment type	
		OR	95% CI
High Exertion (hard/very hard vs. ref: light/medium)	Unadjusted	4.53	(1.37, 15.01)
	Fully adjusted[a]	4.08	(1.20, 13.80)
	Task-adjusted[b]	3.36	(0.77, 14.61)
Specific HRI Symptoms (heavy sweating and/or light-headedness vs. ref: none)	Unadjusted	2.71	(1.10, 6.69)
	Fully adjusted[c]	3.52	(1.34, 9.28)
	Task-adjusted[d]	1.36	(0.34, 5.47)

[a]Adjusted for age, gender, and general health

[b]Adjusted for same variables as indicated in footnote 'a', plus task

[c]Adjusted for age, gender, exertion, hydration frequency, and general health

[d]Adjusted for same variables as indicated in footnote 'c', plus task

Task sub-analysis 4: The two-category task variable was added to the exertion model as the main exposure variable, and mediation by payment was explored. In this analysis, the odds ratios represented the odds of the outcome in harvesters compared to the odds of the outcome in workers who reported other tasks. The odds of a harvester working hard, compared to the odds for an "other" worker, were 3.03 (95% CI: 1.03, 8.93) and were 1.49 (95% CI: 0.40, 5.53) when adjusted for payment.

Break Length Sub-Analysis

The odds ratios obtained when afternoon break length was evaluated as an outcome variable are reported in Table 10. When adjusted for gender, age, and general health, the odds of a piece rate worker taking an afternoon break shorter than ten minutes in length are 2.05 (95% CI: 0.86, 4.89) times the odds of an hourly worker doing so.

Table 10. Odds ratios (95% confidence intervals) of the length of the afternoon break in piece rate compared to hourly workers (n=94).

Outcome	Model	OR (95% confidence interval) of association of outcome with payment type	
		OR	95% CI
Afternoon break length (shorter than 10 min vs. ref: 10 min or longer)	Unadjusted	1.82	(0.80, 4.17)
	Minimally adjusted[a]	1.89	(0.81, 4.40)
	Fully adjusted[b]	2.05	(0.86, 4.89)

[a]Adjusted for age and gender

[b]Adjusted for age, gender, and general health

Exertion Sub-Analysis

Exertion sub-analysis 1: Only a few participants appeared to have heart rate data that was plausibly collected while they were resting, and there is no notable correlation between these "resting" heart rates and those heart rates collected when the participants were presumably

working. There is also no obvious correlation between heart rates collected when observation participants were thinning apples and when they were harvesting nectarines.

Given that there was limited ability to detect a trend in task-related heart rates on the days of observation, there was even more limited ability to relate these heart rates to the self-reported general exertion levels for the past week. No trend was detected descriptively, even when BMI, general fitness level, age, and gender were considered.

Exertion sub-analysis 2: Observation participants' reported task and exertion levels on two different dates were compared (Table 11). Notably, no included observation participants reported a lower level of exertion on 8/01 (when they were largely harvesting nectarines) than they did on 7/17 (when they were largely thinning apples). Nine of the 17 included observation participants did not change their reported level of exertion between the two survey dates—many of these nine participants reported that both thinning apples and harvesting other tree fruit were a "medium" level of difficulty (note: one participant reported that he/she was thinning apple *blossoms*, but this may have been an error considering that his/her peers reported thinning apples). One participant said both thinning apples and harvesting other tree fruit were a "light" level of difficulty. All observation participants were paid hourly, so this analysis is controlled for payment.

Exertion sub-analysis 3: The exertion variable was left out of the (otherwise) fully adjusted hydration frequency model, to determine if exertion might be mediating the association between payment and hydration frequency. The effect estimate dropped from 0.31 (95% CI: 0.12, 0.79) to 0.29 (95% CI: 0.12, 0.72).

Table 11. Longitudinal change in observation participants' self-reported task and exertion.

Reported variable	For week preceding 7/17/13:	For week preceding 8/01/13:	Degree of difference[a]
Task	other tasks with apples/cherries/other tree fruit	harvesting other tree fruit	
Exertion	**light**	**very hard**	***
Task	thinning cherries	thinning apple blossoms	
Exertion	**light**	**hard**	**
Task	harvesting cherries	harvesting other crops	
Exertion	**light**	**hard**	**
Task	thinning apples/cherries/other tree fruit	harvesting cherries/other tree fruit/blueberries	
Exertion	**hard**	**very hard**	*
Task	thinning cherries	thinning other tree fruit	
Exertion	**light**	**medium**	*
Task	thinning apples	harvesting apples	
Exertion	**light**	**medium**	*
Task	thinning cherry blossoms	weeding apples	
Exertion	**light**	**medium**	*
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apple blossoms	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**medium**	**medium**	-
Task	thinning apples	harvesting other tree fruit	
Exertion	**light**	**light**	-
Task	thinning apples	thinning apples	
Exertion	**I don't know**	**medium**	.

[a]The "degree of difference" represents by how many levels of exertion the response changed. Possible responses were "light," "medium," "hard," and "very hard." *** indicates that the response changed by three levels; ** indicates the response changed by two levels, etc. – indicates no change.

Alcohol Consumption Sub-Analysis

When gender, age, general health, exertion, hydration frequency, and the number of alcoholic drinks consumed in the past week were adjusted for, the odds of a piece rate worker reporting specific HRI symptoms, compared to the odds of an hourly worker doing so were 3.95 (95% CI: 1.32, 11.83) (Table 12).

Table 12. Odds ratios (95% confidence intervals) for HRI symptoms in piece rate compared to hourly workers, when controlled for the number of drinks consumed per week.

Outcome	Model	OR (95% confidence interval) of association of outcome with payment type		
		OR	95% CI	n
Specific HRI Symptoms (heavy sweating and/or light-headedness vs. ref: none)	Fully adjusted[a]	3.93	(1.32, 11.67)	96
	Drink-adjusted[b]	3.95	(1.32, 11.83)	94

[a]Adjusted for age, gender, exertion, hydration frequency, and general health

[b]Adjusted for same covariates as listed in footnote 'a', plus the number of alcoholic drinks/week

HRI Training Sub-Analyses

When workers' experience in agriculture was compared to their receipt of HRI training, an unexpected trend was descriptively noted (Table 13). Among participants who've worked two seasons or fewer, a small percentage reported having been trained; unexpectedly, the percentage of participants reporting no training seems to increase, not decrease, as workers gain experience, up to three to nine seasons of experience. Not until workers report ten or more seasons of experience do we note a dramatic shift in the percentage reporting receipt of training.

When age, gender, general health, hydration frequency, exertion, and training were adjusted for in the secondary symptoms model, the odds of a piece rate worker, compared to an hourly

worker, reporting experiencing HRI symptoms were 0.19 (95% CI: 0.04, 0.93). The coefficient of the training variable itself is not significant.

When age, gender, exertion, distance to the toilet, health conditions associated with increased thirst, and training were adjusted for in the hydration frequency model, the odds of a piece rate worker, compared to an hourly worker, drinking infrequently were 0.33 (95% CI: 0.13, 0.84).

Table 13. Percentage of workers who have received HRI training within the last year, stratified by the number of seasons of agricultural experience (n=94).

	Receipt of HRI training (%)		
No. of seasons worked in agriculture	No (n=62)	Yes (n=32)	Total (n)
< 1	71.4	28.6	7
1-2	72.7	27.3	11
3-5	85.7	14.3	14
6-9	86.7	13.3	15
≥10	51.1	48.9	47

Body Mass Index Sub-Analysis

Our height and weight survey questions had high validity. Among observation participants, the mean percent agreement was 97.2% for weight and 96.6% for height. When BMI was calculated from the responses to the survey height and weight questions and compared to BMIs calculated from the field measurements taken by research staff, mean percent agreement was 92.1%. The range of BMIs for all participants was 18.7-40.3 kg/m^2, with a mean of 27.6 kg/m^2 and a median of 27.2 kg/m^2 (n=94). When BMI was added to the primary symptoms model as a continuous variable, there was no significant effect on the odds ratio with a one-unit change in BMI. There was also no significant effect when BMI was added to the model as a dummy variable, comparing the categories of "normal weight" (BMI: 18.5-24.9 kg/m^2) to "overweight" (25.0-29.9 kg/m^2) to "obese" (≥30.0 kg/m^2). The categories contained 25.5%, 47.9%, and 26.6% of participants, respectively.

DISCUSSION

In our study, piece rate workers reported higher levels of exertion and higher prevalence of specific HRI symptoms than hourly workers, but also reported drinking water more frequently than hourly workers. With the exception of frequency of water consumption, these results are consistent with our a priori hypotheses. HI_{max} values were not very variable over the period of survey deployment, and all but one participant appear to have been laboring in HI_{max} conditions that are within OSHA's lowest risk level. No significant interaction between payment and HI_{max} was detected.

The Discussion section will review these results in greater detail, acknowledge the strengths and limitations of this study, and conclude with recommendations for future research and the potential policy implications of the study's results.

Interpretation of Results

Association between payment method and exertion

Our *a priori* hypothesis was that piece rate workers were more likely to report having worked hard than hourly workers. Our results are consistent with this hypothesis. After adjustment for gender and age, the odds ratio was closer to null, suggesting that some of the observed association can be described by demographic variables. The estimate for the odds ratio remained essentially unchanged with further adjustment for general health, suggesting that piece rate workers may be working harder than hourly workers regardless of how healthy they perceive themselves to be.

The confidence intervals of these effect estimates are rather wide, which may in part reflect the relatively small sample size of the study.

Our results are consistent with previous literature suggesting that piece rate workers have increased exertion compared to hourly workers. Toupin et al. tested a theoretical model that described the dynamics of incentives, behavior, effort, and productivity among piece-rate brushcutters. They postulated that productivity depends in part on worker effort, which is measured by heart rate and influenced by behavior (e.g. working at a fast or slow pace). Behavior, in turn, is influenced by monetary incentives, weather conditions, and worksite factors (Toupin et al., 2007). Our study saw no significant impact of HI_{max} on exertion, leaving just monetary incentives and worksite factors from Toupin et al.'s model to explain the significant elevation in reported exertion in our piece-rate workers relative to hourly workers. Mercier states that piece-rate workers in the logging industry set financial goals for themselves to achieve over the course of a season, which they divide into weekly salary objectives. When site factors inhibit productivity, workers can either work slower and fail their goal, or increase their effort to reach their goal (Mercier, 2002). In contrast, Toupin et al. found that piece-rate brushcutters' mean relative heart rates (RHR) were inversely related to site obstacles, suggesting that brushcutters were working hardest in the easiest terrain, to compensate for lost productivity in the more difficult plots (Toupin et al., 2007). The brushcutters' mean RHR were 50% (standard deviation: 13.7%)—quite high considering that the maximum acceptable RHR for an eight-hour shift is 24.5% (Toupin et al., 2007; Wu & Wang, 2002). While Toupin et al. and Mercier disagree about exactly how site factors relate to worker effort—possibly due to differences in the tasks and populations they studied—they do agree that monetary incentives are the driving force behind why workers change their behavior in response to site factors. Our study could not directly measure site factors, but it appears likely that piece rate workers were subconsciously responding to the conditions at their workplaces in order to be productive enough to achieve their

compensation goals. The significant elevation in exertion in piece rate workers seems largely associated with the monetary incentives created by piece rate pay.

Due to the cross-sectional nature of the survey, the direction of the association cannot be determined. In fact, as we discuss in the Payment section (page 68), worksite managers may assign individuals to piece rate contracts specifically *because* they have demonstrated that they are hard or fast workers in the past. Regardless, workers must sustain their status as hard/fast workers once they've been assigned to piece rate contracts, or else they could lose the contracts; therefore, from the perspective of risk factors for HRI, it may not matter whether exertion initially leads to piece rate pay or vice versa. There is likely a positive feedback loop at play.

Association between payment method and hydration

We hypothesized that piece rate workers would drink less often than hourly workers, due to incentives to limit break time. The association noted, however, is in the opposite direction—suggesting that in the survey population, piece rate workers reported drinking *more* frequently than hourly workers. Attempts to control for potential confounding by exertion attenuated the association slightly, but the fully adjusted model still suggests that piece rate workers drank more frequently than hourly workers, even after adjustment for gender, age, the distance to the toilet, and the presence of health conditions or medications associated with increased thirst. The results suggest that piece rate workers might be maintaining more healthy levels of hydration than hourly workers, given that they drank more frequently, exclusive of their substantially greater levels of exertion. While interpretation should be contingent upon more sophisticated measurements of hydration status, these results suggest that piece rate workers might be better able to be productive than hourly workers, regardless of monetary incentives. Among forest workers, dehydration was associated with a 12% decrease in productivity (Wasterlund,

Chaseling, & Burstrom, 2004). Potential gains in productivity, however, might be counter-balanced by development of HRI.

One possible explanation for the unanticipated direction of the association could be that the (probable) decreased level of supervision experienced by piece rate workers (Roka, 2009), relative to hourly workers, allowed them to feel more comfortable taking drinks while working. Survey data does not strongly support this theory, however. A survey question asked "*Do you feel like you are allowed to take extra breaks if you need to rest or drink water?*" There was not much variability in response across payment type—73% of hourly and 75% of piece rate workers answered "*yes*".

There was, however, variability across payment type for receipt of HRI training—40% of piece rate, compared to 27% of hourly workers, reported receiving HRI training within the last year. It has been demonstrated that workers who have been trained about the role of hydration in HRI drink more frequently (Brake & Bates, 2003). A secondary analysis that controlled for the receipt of HRI training noted slight attenuation in the effect estimate toward the null (adjusted OR: 0.33; 95% CI: 0.13, 0.85), suggesting that HRI training might partially explain the finding that piece rate workers reported drinking more often than hourly workers (page 47).

These results must be interpreted with caution, as the survey question measuring hydration frequency may not be valid. The validity of this question is discussed on page 62. However, in a question inquiring why workers drank less water than they wanted to at work, 73% of piece rate workers and 65% of hourly workers indicated that they drank the amount that they wanted to, which lends tenuous support to the suggested interpretation that piece rate workers are drinking "enough." Nonetheless, previous research has noted an association between dehydration and

higher levels of perceived effort (Szinnai, Schachinger, Arnaud, Linder, & Keller, 2005), so if hourly workers were truly more dehydrated than piece rate workers, we might have expected their reported exertion levels to have been higher.

It is unclear whether adjusting for exertion is appropriate in this model. In Aim 1, an association between payment and exertion was noted; however, due to the cross-sectional nature of this study, no conclusions about directionality can be made. If payment method precedes exertion in the causal pathway, then controlling for exertion in the hydration frequency model could introduce over-adjustment bias, as exertion could mediate the association between payment method and hydration frequency. If, however, exertion affects both payment method and hydration frequency independently, then controlling for it in this model is warranted. In a secondary analysis (*Exertion sub-analysis 3:* page 45), the exertion covariate was left out of the fully adjusted hydration frequency model, to determine if exertion might be mediating the association between payment and hydration frequency. The effect estimate dropped from 0.31 (95% CI: 0.12, 0.79) to 0.29 (95% CI: 0.12, 0.72). Given that controlling for exertion seems to produce a null-biased estimate of the association, exertion may be a mediator of the association between payment and hydration frequency. Including exertion in the primary analysis may have adjusted away any indirect effects of pay on hydration frequency (via exertion), but since a significant effect estimate remained, worker exertion does not appear to be sufficient to fully explain why piece rate workers reported drinking more frequently than hourly workers.

The distances to water and to the toilet were both considered for use as potential covariates of the relationship between piece rate pay and the frequency of hydration. Given our relatively small sample size, we wanted to limit the number of covariates we adjusted for, to preserve statistical

power. We compared the validity of the distances to water and to the toilet questions to determine which to include.

The toilet in the observed orchard was attached to a vehicle and could be relocated by the foreman when the workers moved to a new block. Although the foreman tried to position the toilet in the middle of the block, blocks were large enough that workers at the periphery of the block might have had to walk further than workers closer to the center of the block. Like the toilets, the employer-provided water source was portable and the distance varied over the course of the day. Both the distance-to-toilet and distance-to-water questions appear valid, with 100% agreement when "matching" was defined as the accurate selection of a distance of either five minutes or less or more than five minutes away (Table 2).

Although both the distance-to-toilet and distance-to-water measures were validated, and although both varied over the course of the day as the workers and the facilities moved around the orchard, the distance-to-toilet measure was determined to be the best measure for this study. The distance-to-water measure has an additional uncertainty factor: many participants had their own water with them, but began using employer-provided water later in their shifts as their own water ran out. This level of detail was challenging for staff to capture, so the distance-to-toilet measure was used in the model for hydration frequency instead. The distance-to-toilet and distance-to-water measures were moderately correlated (correlation coefficient = 0.405), likely because the foreman sometimes parked the toilet and the water close to one another.

Association between payment method and self-reported HRI symptoms

Our results suggest that piece rate workers had almost four times the odds of experiencing dizziness, light-headedness, fainting, or heavy sweating, compared to hourly workers. These

results are consistent with our hypothesis. However, when asked more generally about HRI symptoms (without specifying what those symptoms might be), piece rate workers were significantly less likely to report experiencing symptoms associated with working in the heat than hourly workers.

The marked difference in both the magnitude and direction of the association observed for the two symptoms models is noteworthy. One possible reason for the difference could be participants' knowledge of HRI. The outcome variable in the secondary symptoms model assumes that the respondent recognizes symptoms of HRI ("*In the past week, did you ever experience any health symptoms or illnesses that you think may have been related to working in the heat?*"). Participants may not have realized that certain symptoms they experienced were related to heat exposure, and thus may have responded "*no*" to this question. Indeed, as shown in Table 3, of the 82 participants who responded "*no*" to the secondary symptoms outcome variable question, 22 in fact indicated in the primary symptoms question that they'd experienced specific symptoms related to heat exposure. Support for the "unfamiliarity" theory comes from the fact that participants misclassified themselves as "*yes*" responses to the secondary symptoms question as well—of the 13 participants who said "*yes*", only six actually reported specific symptoms that would classify them as symptomatic in the primary symptoms model. Given that a greater fraction of piece rate workers (about 40%) than hourly workers (about 27%) reported having received HRI training in the last year (Table 5), it is possible that the association is confounded by HRI training. In a secondary analysis, training was added to the secondary symptoms model as a potential confounder, and it did slightly affect the effect estimate (page 47). Although adjusting for training had a very mild impact on the odds ratio (the OR changed from 0.20 to 0.19), given that the unadjusted estimate was slightly closer to null than the adjusted

estimate, training may have been a negative confounder of the association between payment and secondary symptoms. This, unfortunately, strengthens rather than explains the magnitude of the difference between the primary and secondary symptoms models.

Given that we cannot be sure that receiving HRI training is equivalent to knowing what symptoms are related to working in the heat, it seems reasonable to consider the results of the primary symptoms model to be more valid than those of the secondary symptoms model. The former is not predicated upon knowledge of which symptoms may be related to heat exposure.

Table 14 shows how the reported specific symptoms of HRI were stratified across the two payment schemes. Although none of the participants reported having fainted in the week preceding their survey, participants did report experiencing dizziness or light-headedness and heavy sweating. Approximately twice as many piece rate workers as hourly workers reported experiencing these symptoms. While sweating does not necessarily mean that an individual is going to experience severe HRI, it does signify that the individual is having a biological response to heat exposure (i.e. heat strain). Piece rate workers appear to have a higher prevalence of this physiological response to heat than hourly workers.

Table 14. Stratification of specific symptoms reported, by payment scheme.

Specific symptoms	Hourly (%)	Piece (%)	Total (%)
Dizziness or light-headedness	2.0	4.2	3.1
Fainting	0.0	0.0	0.0
Heavy sweating	18.4	37.5	27.8

Our results suggest that piece rate workers may be at increased risk of developing symptoms that may lead to HRI. However, given the cross-sectional survey design, no conclusions about

causality can be made. It is possible that employers more frequently assign workers who are prone to illness or injury to piece rate contracts than to hourly contracts, although no evidence—anecdotal or otherwise—can be found to support that. If true, then it appears that employers assess employee health in a systematically different way than employees perceive their own health—a slightly greater fraction of piece rate (31.3%) than hourly (28.6%) workers reported their general health as "*excellent*" or "*very good*", and the association between payment and specific symptoms persists when the model is controlled for participant-perceived general health.

In sub-analyses (pages 47-48), we explored alcohol consumption and BMI as potential precision variables in the primary symptoms model, as alcohol use and obesity have been described as risk factors for exertional HRI (Bonauto et al., 2007). Inclusion of the alcohol consumption and BMI covariates did not have a substantial impact on the effect estimate, and may not have played important roles as risk factors for HRI symptoms in this survey population. We could not validate the alcohol consumption question. Although the use of a self-guided, computer-based survey format may have made participants feel more comfortable reporting their alcohol use than an in-person interview (Preisendörfer & Wolter, 2014), underreporting is still possible and could have impacted the results.

For both symptoms models, the odds ratio for the age of the participants was statistically significant. In the primary symptoms model, when all other covariates were held constant, there was a 5% decrease in the odds of reporting specific symptoms for a one-year increase in age (OR: 0.95, 95% CI: 0.91, 0.99). The effect was similar in the secondary symptoms model, with an 8% decrease in the odds of reporting symptoms for a one-year increase in age, when all other variables were held constant (OR: 0.92, 95% CI: 0.87, 0.98). It is possible that older workers take more precautions to protect themselves from HRI. As one might expect, the older workers

are the ones who have spent the most seasons in agriculture. The mean (standard deviation) age of workers who have spent two or fewer seasons in agriculture is 26.4 (6.9) years; among workers who have spent ten or more seasons in agriculture, the mean (standard deviation) age is 47.7 (9.6) years. Again, there does seem to be an association between the most experienced workers (i.e. ≥10 seasons) and receipt of HRI training, and training might have helped workers learn preventative measures to protect themselves from HRI.

Decreased willingness to take breaks was hypothesized as a possible mediator of the effect between piece rate pay and HRI. The relationship between payment scheme and break length was not included in the primary analyses for two reasons: (A) The survey asked about morning, lunch, and afternoon break lengths, but no precedent could be found in the literature about the best way to consider break length in the aggregate; and (B) The survey questions asked about the "usual" break length, rather than that of the past week.

Washington State agricultural workers are entitled to one ten-minute (paid) break for every four hours of work, and a 30-minute (unpaid) lunch break if they work more than five hours during a shift (WAC 296-131-020). Nearly all (n = 93) participants reported that their lunch break was 30 minutes long. Thirty-six participants reported that they don't usually take an afternoon break, perhaps because they may not work for an additional four hours following their lunch breaks. Regardless, afternoon break length was considered as a risk factor for HRI in a sub-analysis (page 44), with the hypothesis that piece rate workers would take shorter afternoon breaks than hourly workers. Our results suggest that piece rate workers were less likely to take a longer afternoon break than hourly workers, but this finding was not statistically significant, possibly due to limited variation brought about by our small sample size. It is plausible that piece rate workers are laboring through their afternoon break. One worksite manager stated that if his

employees work by piece rate, "they decide their breaks, and usually they don't take breaks, and (they) have lunch for 10 to 15 minutes" (P. Palmández, personal communication, Jan. 24, 2014). Alternatively, piece rate workers might have ended their shifts earlier than hourly workers, and thus did not work an additional four hours after lunch to "earn" a ten minute break.

Effect Modification by Heat Index

We did not observe significant effect modification by heat index in our study, suggesting that the effect of payment on our outcomes did not differ by the level of the heat index (above or below 85°F). We do believe, whether through interaction with payment or not, that the ambient conditions are a risk factor for HRI; however, lower heat indexes may be more dangerous than is typically acknowledged. Although only one of our participants labored under HI_{max} conditions above OSHA's lowest risk level (Occupational Safety & Health Administration, 2014), 31% of participants reported symptoms of HRI. In their assessment of WA State workers' compensation claims for HRI from 1995-2005, Bonauto et al. noted that the median maximum daily temperature for outdoor claims (n=377) was 85°F, and 25% of claims occurred below 77°F (Bonauto et al., 2007). The temperate climate of the Pacific Northwest does not disqualify WA state workers from being vulnerable to HRI. Our HI_{max} range was fairly narrow and was dichotomized at the median. The lack of variability, together with the evidence that HRI can and does occur at low heat indexes, may explain why we did not observe significant effect modification. As climate change increases the frequency and intensity of heat waves in WA—especially during the summer—we might expect vulnerability of agricultural workers to increase further still (Dalton, Mote, & Snover, 2013; E. Jackson et al., 2009).

Our HI_{max} was truncated by shift time, so the HI_{max} did not necessarily reflect the average of the true maximum daily heat indexes for the week. The maximum daily heat indexes often occurred

between 1:00 and 5:00 pm. About 69% of the time, the shifts were truncated at 3:00 pm, so the value included in the HI_{max} calculation was not always the actual maximum heat index for the day. There is some question as to whether this truncation was appropriate, as sustained heat occurring outside the work day can impact workers' ability to recover for the next shift (Quandt, Wiggins, Chen, Bischoff, & Arcury, 2013). This truncation, however, did not change the values of the HI_{max} very much. The shift-truncated HI_{max} ranged from 82.4°F to 93.1°F, with a mean of 85.8°F. The true (non-truncated) HI_{max} ranged from 82.4°F to 95.7°F, with a mean of 86.2°F. For both, the median HI_{max} was 85.4°F.

Limitations

Study Design

One limitation of this thesis is its reliance on a survey of cross-sectional design, which limits the ability to make inferences about temporal associations between payment and outcomes or to draw conclusions about causality. The cross-sectional design also necessitates reliance upon retrospective data, which is more prone to recall bias. Recall bias has hopefully been limited by the use of questions that ask participants about the "past week"—a relatively short time period. Residual recall bias is not anticipated to affect piece rate workers and hourly workers differently.

Our study relied on self-reported survey information, which sometimes had low validity. This may have particularly impacted our hydration frequency estimation. Validity analyses are discussed in more detail beginning on page 62.

In logistic regression, outcome variables need to be binary, and we often found it pertinent to dichotomize the covariates as well. While necessary for our intended analyses, dichotomization could have led to some information loss, owing to our relatively small sample size.

There is also possible selection bias—worksite managers had to allow their workers to participate, and then workers had to consent as well. This self-selection could affect the internal validity of the study if workers/worksites that chose to participate are fundamentally different from those who declined. During recruitment, candidates were informed that the goal of the study is to learn about how working outside in the heat affects health. It is possible that managers operating worksites with poorer working conditions might have been less likely to agree to participate, and workers who are most concerned about their health may have been most likely to participate. Concerned workers may behave differently than non-concerned workers. A survey question asked, "*How concerned are you about your health being affected by working in hot conditions?*" About 23% responded "*not at all concerned,*" 52% said they were, "*a little bit concerned,*" 19% were "*very concerned,*" and about 7% did not have an opinion. Also, only workers at the worksite could be recruited; if some workers were on leave recovering from recent heat exposure (for example), this may have introduced selection bias toward a healthier group.

The external validity of these results are limited if the participants are not representative of the larger population. The U.S. Department of Labor administers the National Agricultural Workers Survey, through which demographic information about the general U.S. crop workforce is available. The most recent publically available data is from 2007-2009. Table 15 contrasts the demographic characteristics of national agricultural workers (National Center for Farmworker Health, Inc., 2012; U.S. Department of Labor, 2014) and those of this survey population. The survey population appears to contain more foreign-born workers, more females, and less educated workers than the national population. Thus, this survey may not be entirely representative of the broader national agricultural workforce.

Table 15. Contrast of the demographic characteristics of the survey population, compared to the national agricultural workforce.

Characteristic	National Population[a]	Survey Population
Percent born in Mexico	68%	91%
Percent male	78%	53%
Average age (years)	36	41
Percent with higher education	9%	2%

[a](National Center for Farmworker Health, Inc., 2012; U.S. Department of Labor, 2014)

Validity of Survey Questions

The effect estimates are based entirely on data derived from answers to the survey questions (with the exception of the heat index data), so the interpretation of the effect estimates depends on the validity of the survey questions.

Hydration frequency

The question "*In the past week, how often did you usually drink water at work?*" served as an estimate of the frequency of hydration. In validity testing, percent agreement was 31% (Table 2). This question was difficult to validate because the observed frequency generally varied over the course of the day, and it is hard to know how participants might have averaged out those variations to come up with a "usual" frequency to report. Further challenge stemmed from the fact that staff were unlikely to have captured every discrete time that a participant drank. For this validation analysis, the most frequent interval of hydration that was reported on the observation datasheet was selected (i.e. if the notes indicated that the worker drank every hour and a half in the morning, but every half an hour in the afternoon, then every half an hour was used in the analysis). As a sub-analysis, validity was estimated when hydration frequency was dichotomized as it was in logistic regression modeling. Hydration frequencies of "*every 30 minutes or more*" were compared to all other frequencies, and percent agreement improved to 56%. Nonetheless,

overall validity of the hydration frequency question is low, which may partially explain the unexpected finding that piece rate workers reported drinking more often than hourly workers, regardless of exertion.

Another survey question inquired as to the volume of water participants usually drank during their water breaks, but this question proved too difficult to validate.

Accuracy of reports of crop and task

It was noted that participants occasionally reported crop/task combinations that appear unusual for the season. In mid- to late July, participants mostly reported working with cherries (thinning green cherries, harvesting cherries, and doing other tasks with cherries). Participants also reported weeding hops, apples, and other tree fruits; pruning apples; and thinning green apples and other tree fruits. In early August, observation participants were mostly harvesting nectarines. In late August and early September, participants reported harvesting apples, pears, cherries, other tree fruits, grapes, blueberries, and hops; pruning apples, pears, and cherries; sorting and packing cherries, blueberries, apples, pears, grapes, hops, and other tree fruits; thinning green apples; and thinning apple blossoms.

Manual thinning of apples is often done in June and early July in Washington State (Washington State University Extension, 2014); it is unusual that a participant reported this task in late August or early September, but not unheard of (WorkSource, 2014). Apple harvesting in Washington typically begins in early August and continues through November (WorkSource, 2014); participants could have been harvesting the first apples of the season. Cherries are typically harvested in June and July (WorkSource, 2014), so it is unusual that participants reported thinning cherries in mid- to late July.

Most task/crop combinations are plausible, but peculiarities might be explained by study design. By virtue of the way the study was designed, participants were able to select their one "main" job task for the past week, but were able to select as many crops as they wanted for the same time period. Thus, it is plausible that some of the crop/task discrepancies arose because the main task selected did not apply to all of the crops selected. For example, one participant who took the survey in mid-July reported thinning green fruit for apples, cherries, and other tree fruit during the past week. It is unusual to thin cherries in July, but perhaps the participant completed a minor (non-green fruit thinning) task with cherries during the week preceding the survey, and the survey design just doesn't allow for the capture of that level of detail.

Exertion

The question "*How hard has your work been in the past week?*" was used as a proxy for exertion in this study. Percent agreement was just 29% (Table 2); however, this question, like a number of others of similar style, is difficult to validate. Participants were (theoretically) reflecting upon the past week, but research staff were only observing and note-taking on the day of the survey. Furthermore, it may be challenging for field staff to accurately determine the level of exertion that a participant is experiencing. On the days that observations took place, there were three main tasks being conducted: green fruit thinning, pruning branches, and harvesting. Research staff categorized these tasks by exertion, based on consensus. Green fruit thinning was categorized as a medium/moderate exertion task, as was pruning branches (even though pruning was considered slightly more difficult than thinning). Harvesting was categorized as hard/heavy work. One staff member noted that the workers, who were all being paid hourly on the days of observation, were not exerting themselves as much as they would be if they were being paid by the piece. The staff

member also stated that harvesting on piece rate would likely be categorized as very hard work (P. Palmández, personal communication, May 5, 2014).

Perceived exertion can and does have interpersonal variability among participants reporting performing the same task. It could be argued that there is less utility in validating this question than others; a participant who feels that a task is harder than what research staff expect it to be could indeed still be exerting himself in a physiologically important manner. Nonetheless, attempts were made to validate the exertion question.

In a sub-analysis, we attempted to compare responses to the exertion question with heart rate measurements (*Exertion sub-analysis 1:* page 44). However, heart rate did not change in predictable ways between when the observation participants were presumed to be at rest and when they were working, nor was a trend detected between when observation participants were thinning apples and when they were harvesting nectarines. Furthermore, no obvious connections between the objective heart rate measures and the subjective exertion reported could be detected. We could not compare heart rate measures during work to resting heart rate, because resting heart rates were not consistently measured. Unfortunately, the subjective and objective measures of exertion in this study did not cover exactly the same time frame. While the survey question asks about exertion experienced in the past week, the heart rate data were collected for only one day, at discrete time points. Thus, we might not expect to see correlation in the measures anyway, even if the heart rate data and observation notes had been collected properly. Also, although this survey's exertion question was based on the Borg RPE scale question that was used in the Johnson et al. study, they are not the same and cannot be directly compared.

No included observation participants reported a lower level of exertion in early August (when they were largely harvesting nectarines) than they did in mid-July (when they were largely thinning apples) (Table 11). This assessment lends some credit to the assumption that the exertion question is valid, given that field staff themselves classified nectarine harvesting as more difficult than thinning apples. Again, all observation participants were paid hourly on both days of observation, so this sub-analysis was controlled for payment.

The exertion question may not be measuring physical exertion in the manner intended. The question asked how "hard" the work was—it is possible that some participants could have interpreted "hard" as an indicator of the skill required to perform a task. However, given that tasks that require more thought and/or skill tend to be paid by the hour, we can be reasonably assured that most participants did not interpret the question in this way, or else we'd expect to see piece rate workers having lower odds of reporting working hard than hourly workers. Alternatively, it is possible that workers are aware of the general philosophy that piece rate work is "harder" than hourly work, so they might have been reporting that rather than what they actually felt.

Payment type

We investigated the effect of exposure to piece rate pay, and participants appear able to accurately report their payment methods. According to research staff, all observation participants were paid hourly, and 16 out of the 17 eligible for this analysis reported hourly payment.

One potential unexpected finding is that seven workers reported being paid hourly for harvesting. Harvesting is commonly paid by the piece; one staff member who is well-versed in agricultural practices stated that she doesn't know of any grower who pays hourly for harvesting unless the workers are harvesting from a platform or working through the H-2A program (K. Galvin,

personal communication, March 11, 2014). We attempted to determine whether the use of platforms or the H-2A program could explain our potentially abnormal finding. According to field staff, no participants used platforms. No survey question inquired about the workers' H-2A status; however, there was a question asking whether participants lived in the U.S. year-round (H-2A workers are temporary employees who do not reside in the U.S. for the full year). Seven participants reported that they do not live in the U.S. year-round, and are thus potentially part of the H-2A program. Of these seven participants, three reported being paid hourly and four reported being paid by the piece. Table 16 shows their reported tasks and payment methods. While three of the non-residents reported harvesting on hourly contracts, neither platform work nor H-2A workers can fully explain why some harvesters reported hourly payment.

Table 16. The payment type and task reported for participants who stated they do not reside in the US year-round (n =7).

	Payment Method		
Task	**Hourly (n)**	**Piece (n)**	**Total**
Pruning	0	1	1
Harvesting	3	2	5
Sorting	0	1	1
Total	3	4	7

Another potential explanation could be a misunderstanding of the question. The payment question read, "This question is asking about your main job task in the past week. How were you paid for your work?" Hypothetically, workers reported the payment type that corresponded to their reported main job task; however, it is plausible that the question was misinterpreted.

It is also possible that the harvesters reported their payment correctly. Field staff noted that, occasionally, managers might ask the workers to perform tasks that might be considered "out of the ordinary" in order to give them enough work to finish the day or employ them. It is possible that a worker was initially conducting a task that is more appropriate for an hourly contract, but

finished it and was reassigned to harvesting (P. Palmández, personal communication, May 5, 2014). Alternatively, managers may have deliberately assigned some harvesters to hourly contracts. Research staff were able to interview six worksite managers about how they decide which tasks to pay hourly and which to pay by the piece. Managers commonly stated that they pay by the hour when the work needs to be performed carefully and when it is too difficult for them to determine an appropriate piece rate (i.e. when the trees are not uniform in size or fruit density). Tasks that managers said they paid hourly wages for during the summer of 2013 included fruit thinning, pruning, tractor operating, and some harvesting. The harvesting work that was compensated with hourly wages appeared to involve more delicate fruits (e.g. peaches and nectarines), and one manager said he paid hourly when the harvesting work was too slow (i.e. when the workers were harvesting large pears).

Managers stated that they pay by the piece when it is easy to establish the piece rate (i.e. trees are uniform), when they want to incentivize their employees to work quickly or hard, and when the manager wants to decrease the need to supervise the workers. Tasks that managers said they paid by the piece included fruit thinning and harvesting; some managers specified apple and cherry harvesting and one specified apple and peach fruit thinning. Furthermore, when managers need to assign their workers to various tasks, they tend to assign workers who have previously demonstrated themselves to be hard/fast workers to harvesting or other common piece rate tasks.

We assumed that workers in this population did not get to choose their payment method. If they were able to self-select into piece rate contracts, our models would need to control for personal characteristics that might affect both workers' remuneration decisions and their risk of HRI (see the 'Plausible Methods of Action' section, page 7). In late 2013, a workshop was held to share and discuss some relevant results with the observation participants. Six participants attended the

workshop (five were men). Participants were asked if they were ever able to choose whether they were paid by the piece or the hour; none of them had ever had a say in their payment scheme, nor had they ever heard of a farm where the manager allowed the employees to choose.

Clothing worn

In initial hypotheses, clothing was considered as a precision variable in the symptoms models. Dark, thick, non-breathable clothing could increase a worker's risk for experiencing symptoms of HRI (Occupational Safety & Health Administration, 2013). Survey questions were targeted at determining what participants wore while working, but there was limited ability to assess the validity of the questions. Field staffs' observation notes were often not detailed enough to determine whether clothing was light- or dark-colored or whether workers were wearing layers.

Participants often listed various combinations of "*light-colored short sleeved shirt*," "*dark-colored short sleeved shirt*," "*light-colored long sleeved shirt*," and "*dark-colored long sleeved shirt*." It is not clear whether participants were indicating that they wore layers or whether their clothing was variable over the week, and they listed all items they had worn. Given the limited staff observation notes, this question could not be validated to the extent that it could be included in the symptoms models.

Furthermore, fewer than 25% of participants reported wearing pants, but field staff notes indicate that all observation participants were, in fact, wearing pants. This discrepancy was likely due to the way the survey question was constructed. Participants were asked to "*select the type of clothing that (they) have usually worn at work in the past week.*" Participants could then select clothing options from a list; since shirt and pants options were listed together, it appears that many workers made a selection for the type of shirt they wore, then moved on to the next question without addressing their pants. The inability to determine whether participants were

wearing pants or shorts may not be important. A study of outdoor workers laboring under environmental conditions similar to those of this study found no significant difference in body temperature between workers wearing pants and workers wearing shorts (Sinclair & Brownsberger, 2013).

Symptoms of HRI

This thesis relies on self-reported HRI symptoms as the outcome variable for Aim 3. Without an objective assessment, we cannot validate the symptoms questions.

Ability to Control for Confounding by Task

Task could affect the outcome variables in a number of ways. Task is related to the amount of exertion workers must spend to accomplish it. It is also reasonable to anticipate that task is related to the conditions under which workers must labor in order to perform the task (e.g. the level of shade). The level of shade and other conditions might impact how often workers need to drink and/or their ability to dispel excess metabolic heat. Given that the specific task being performed might influence how hard a worker exerts him- or herself, how frequently he/she needs to or is able to hydrate, and whether he/she experiences symptoms of HRI, and also knowing that employers make decisions about payment scheme based on the task and crop with which workers will be engaging, it seems that task should be controlled as a potential confounder in these models. A substantial limitation of this study lies in its limited ability to control for potential confounding by task.

After a number of informational interviews with persons well-versed in the agricultural industry, it was concluded that classifying participants by reported task/crop alone is not descriptive enough to capture the relevant factors. For example, it would be inappropriate to assume that two participants who reported “harvesting apples” as their main task experienced similar work

conditions or levels of exertion. These factors depend on the density of fruit on the tree, the size of the tree, whether the participants were harvesting from the ground or on a ladder, etc. (K. Galvin, personal communication, March 11, 2014; K. Lewis, personal communication; March 31, 2014). The survey was not designed to capture that level of detail, which is a critical limitation.

We conducted several sub-analyses to address this issue as best we could with the data available. We looked at the only longitudinal data collected—that of the observation participants—to determine if their payment varied in a predictable way as task changed from mainly thinning apples in mid-July to harvesting nectarines in early August. Based on anecdotal comments by worksite managers (page 68), we might expect to see apple thinning paid by the piece and nectarine harvesting paid by the hour, since nectarines are delicate. However, observation participants were paid hourly on both survey dates (*Task sub-analysis 1:* page 42). This might be considered mildly supportive of some independence between task and payment method.

We also performed our analyses on a subset of the survey population consisting of harvesters only, in an attempt to control for task (*Task sub-analysis 2:* page 42). Although precision was lost, the effect estimates for primary HRI symptoms and hydration frequency are in the same direction as in the primary analyses, lending some support to the hypothesis that payment method may act as a risk factor for HRI in these workers, independent of task. However, the small sample size makes interpretations difficult. Effort and secondary symptoms outcomes could not be evaluated in these models because of a lack of variation in this small subsample.

We also attempted to control for task as a potential confounder, at the expense of precision, in secondary analyses. Although confidence intervals were wide, adjusting for task does seem to

lead to attenuation of the effect estimate in the exertion and primary symptoms models, lending support to the theory that task may act, at least in part, as a confounder (*Task sub-analysis 3:* page 43). Task, however, does not appear to completely adjust away the effect of payment on the outcome variables, which gives further support to the theory that payment method might affect HRI directly or via other mechanisms, independent of task.

We also explored pay as a mediator of the relationship between task and exertion, hypothesizing secondarily that certain tasks are assigned piece rate contracts, and piece rate pay leads to increased work exertion. Our results suggest that there is some mediation by payment type, although definitive conclusions are difficult to make due to the small sample size (*Task sub-analysis 4:* page 44).

When considered collectively, these analyses seem to provide some suggestions that there are direct effects of payment on the outcome variables, independent of task. Additional support comes from a study of injuries in migrant Hispanic agricultural workers in California, which found that female piece rate workers had a significantly elevated risk of injury relative to hourly workers, independent of job task (McCurdy et al., 2003). Their study, too, may not have captured the relevant workplace factors.

Ability to Control for Effect of Acclimatization

Heat acclimatization improves physiological tolerance of heat exposure (L. L. Jackson & Rosenberg, 2010). It can take up to two weeks for the body to adapt to exertion in heat (Wenger, 1997). A survey question was intended to determine whether workers had been acclimatized at the beginning of the season ("*When you started doing outdoor work this season, did you begin working a few hours per day and gradually increase the number of hours of work?*"). About 65%

of participants reported that they had not. Given, however, that the majority of participants reported starting work for the season prior to the beginning of July, we would not anticipate workers to experience effects specifically brought about by a lack of acclimatization by the time that they took the survey between mid-July and early September. An exception to that statement: acclimatization can diminish after time off or after a few days without working in the heat (L. L. Jackson & Rosenberg, 2010). The survey did not capture the timeline of each participant's recent work history in sufficient detail to determine whether each should or should not be acclimatized. Acclimatization may be an effect modifier of the relationship between payment type and HRI.

Strengths

The cross-sectional study design proved useful for developing new hypotheses; it lent itself to exploring the associations between the exposure (payment) and numerous outcomes in a more efficient manner than would be required by a prospective cohort design.

Our study is fairly unique among studies of HRI in that it incorporates information about the reliability and validity of the survey questions into the interpretation of our results. This has enabled us to approach our results with appropriate reservation where our findings suggest that the survey questions may not be fully valid. For example, we note that the question about the frequency of hydration is likely not valid. Frequency of hydration questions have been utilized in other studies of HRI, but they do not appear to have validated the questions (Fleischer et al., 2013; Stoecklin-Marois, Hennessy-Burt, Mitchell, & Schenker, 2013). Our finding suggests that researchers should attempt to use objective measures of hydration in the future.

An interesting secondary finding (non-hypothesized) was that, despite a mandate in the Outdoor Heat Exposure rule, the majority of our participants reported that they had not received HRI

training. It is possible that the workers did in fact receive the training but did not recognize it by that name; our study, unlike that of Stoecklin-Marois, et al., did not test workers' knowledge of HRI (Stoecklin-Marois et al., 2013), which might have provided a clearer sense of workers' familiarity with HRI. If true, however, our findings might indicate that the training mandate might benefit from re-evaluation. It should be ensured that employers have easy access to effective training materials. The development of a program that provides positive incentives to employers to fulfill the training mandate might also prove beneficial. If necessary, more stringent enforcement of the HRI training rule may be necessary in order to ensure compliance, but given how resource-intense inspections can be, the other strategies might be considered first.

Finally, this study provides one of the first known investigations of the impact of piece rate pay on heat-related illness. This study has generated a number of hypotheses about the potential relationship between payment method and HRI, and will set the stage for future research by providing recommendations for how best to objectively study this suggested association.

CONCLUSION

Persons engaged in crop production and support activities are at markedly greater risk of death from HRI than other sectors, at a rate of 0.39 deaths per 100,000 full-time equivalent workers (FTE), compared to 0.02 deaths/100,000 FTE for all industries (Luginbuhl, Jackson, Castillo, & Loringer, 2008). The precise prevalence of non-fatal HRI among agricultural workers is not known, since the more mild stages of HRI typically go unreported (L. L. Jackson & Rosenberg, 2010). We also do not know exactly what impact non-fatal HRI has on either long-term worker health or workplace productivity, although heat exposure has been shown to negatively impact physical and cognitive performance (Hancock & Vasmatzidis, 2003; Sahu, Sett, & Kjellstrom, 2013; Sawka, Francesconi, Young, & Pandolf, 1984). Yet HRI is a significant occupational health and safety concern because it can lead to fatalities, and possibly also to other detriments to worker and workplace well-being. Without action, the impact of HRI will likely be felt more heavily in Washington State in the years to come. The impact of HRI could become increasingly relevant as climate change increases the frequency and intensity of extreme heat events in even the currently temperate climate of the Pacific Northwest (Adam-Poupart et al., 2013). Also, farmworkers are already considered a vulnerable population in the U.S. Most U.S. crop laborers are migrant, impoverished, and have had limited educational opportunities (Stoecklin-Marois et al., 2013). Furthermore, some workers have cultural beliefs that may serve as barriers to effective HRI treatment (Lam et al., 2013). For these reasons, it is important to identify risk factors for HRI among agricultural workers.

Our results indicate that piece rate workers may be at increased risk of experiencing HRI, compared to their hourly-paid peers. The pathway by which piece rate payment may increase the risk of HRI may be related to increased exertion among piece rate workers. This exertion may

lead to elevated metabolic heat levels in piece rate workers, even when environmental conditions are relatively temperate. The direction of the relationship between payment and exertion could not be definitively determined, but it appears likely that they have a positive feedback relationship, whereby the hardest workers may be the most likely to earn piece rate contracts, but also continue to be incentivized to work hard once on a piece rate contract. Although our limited ability to control for confounding of the association between payment and outcome by task was a significant limitation of this study, a series of secondary analyses suggest that there is some direct effect of payment on the outcome variables, independent of task.

While a hydration frequency question of limited validity tempers the significance of the result, we did report that piece rate workers were drinking more often than the hourly workers, despite being controlled for increased exertion. We found that the increased report of HRI training among piece rate workers might partially explain why they appear to drink more frequently. HRI training might be having its intended effect and teaching workers how to take steps to prevent HRI. However, overall, only 35% of our sample reported having received HRI training within the last year, despite a mandate in the WA State Outdoor Heat Exposure rule that all agriculture workers be trained.

Due to the cross-sectional nature of our survey, the results, while intriguing, are hypothesis-generating and contingent upon confirmation. Recommendations for future research are in the next section.

RECOMMENDATIONS

Suggestions for Future Research

This hypothesis-generating study found associations with intriguing potential ramifications for occupational health and safety. These associations, however, need to be confirmed by additional research. Agricultural work is, by its nature, quite transient. Workers' activities are guided by the crop and the season; their task, payment, and risk factors for HRI fluctuate over time. A study of longitudinal design would be better equipped to assess workers' risk of HRI. Furthermore, better tracking of workers' activities over time would allow for better analysis of the effect of acclimatization on exertional HRI.

We found that assessments of hydration by self-report are not sufficiently valid. Future research efforts should incorporate an objective, physiologic measure of dehydration. Other studies have utilized urine-specific gravity measurements to assess levels of dehydration (Hunt, Parker, & Stewart, 2014). While such methods were considered for the current study, they were not implemented out of concern that rates of participation would be lower, given the more invasive nature of the test and the potential association of urine sample collection with drug testing.

Future research efforts might consider utilizing a different measure of exertion. Researchers at the University of Washington are currently comparing the validity of the Borg RPE and OMNI scales against heart rate measurements among Hispanic apple harvesters (K. Galvin, personal communication, May 5, 2014). Should they determine that a survey-based question is a sufficiently valid measure, then future research should make use of it. Heart rate monitoring is more resource intensive, but should be used if resources are available.

Another consideration is worker productivity, which might be expected to correlate with exertion. Again, the primary reason employers use piece rate pay is to incentivize workers to be more productive (Toupin et al., 2007). A small field study of agricultural workers in Yakima Valley, WA found that the productivity increase for piece rate versus hourly workers was between 20 and 23% (Shi, 2010). This is line with productivity estimates for other industries; for example, tree planters in British Columbia on piece-rate contracts planted 20% more trees than their hourly-paid coworkers (Shearer, 2004). Heat exposure may impact coordination, strength, endurance, and other worker characteristics crucial for productivity (L. L. Jackson & Rosenberg, 2010). Hydration status also impacts productivity (Wasterlund et al., 2004). If the association reported with our crude hydration frequency measure did prove accurate (following more precise hydration status assessments), it would be interesting to quantify how the positive effects of exertion and hydration balanced with the negative effects of increased symptoms of HRI to impact overall productivity among piece rate workers. Research that could quantify the effect on productivity following onset of HRI could be invaluable as a tool for communicating with employers in the future. Employers use piece rate contracts as a means to incentivize workers to exert themselves and increase their productivity; however, if there is a peak in exertion after which point the effects of HRI begin to negatively impact productivity, employers might be more willing to consider modifying the use of piece rate contracts.

Future versions of this survey should contain a revised version of the clothing question. Participants were allowed to select as many options to describe their clothing as they wanted in the current version; consequently, it is not clear whether participants were indicating that they were wearing layers, or simply listing all of the different things that they had worn in the week preceding the survey. Future research should take greater advantage of the opportunity for

branching questions that tablet-based surveys afford. For example, the leading question could ask, “How many layers of shirts do you usually wear in the morning?” The computer will allow the participant to select only the specified number of shirt options in the subsequent question. Separate questions should be used for morning and afternoon clothing options, in order to better capture whether workers attempt to adapt to warming weather over the course of the day by removing layers. Separate questions should also be made for shirt versus pants options, since many participants forgot to list what type of pants they were wearing in the current survey. Researchers could also consider photographing the workers to document their clothing.

This survey did not ask participants to report their H-2A program status, but it is known that seasonal and migrant workers are more vulnerable to occupational injury and illness, including HRI (Stoecklin-Marois et al., 2013). Future studies might benefit from including a question about H-2A status; perhaps H-2A status is an effect modifier of the relationship between piece rate pay and HRI.

Future studies should also make substantial efforts to fully characterize the tasks workers are performing. In this study, we discovered that, for example, “harvesting” is not a descriptive enough term to assess the workers’ expected exertion and access to shade. Details about the tools the worker used to accomplish the task might be useful to collect (e.g. was the worker harvesting from the ground, a ladder, or a platform? Was the worker harvesting by hand or with a mechanized harvester?)

Finally, this thesis relied solely on self-reported HRI symptoms, but objective measures of core temperature and the degree of sweating might provide more valid estimates of the prevalence of HRI symptoms.

Suggestions for Policy Changes

The following policy recommendations are made with acknowledgement that this study did not find a conclusive link between payment and HRI; these recommendations are relevant contingent upon confirmation of the association by future research.

A majority of our participants stated that they had not been trained about HRI, despite a requirement that employers provide such training in the Outdoor Heat Exposure rule. We recommend ensuring that existing training materials are being disseminated to employers, and that new, more effective modules be adapted as they become available. Employers may also take advantage of the free on-site consultation and training services offered by WA State's Division of Occupational Safety and Health in order to meet this requirement and help keep their employees healthy and productive (WA State Dept of Labor & Industries, 2014).

Once research has more fully characterized the impacts of heat exposure on the productivity of piece rate workers, it might be useful for industrial economists to develop economic models that weigh the gains from incentivizing employees to work harder/faster against the costs of lost productivity and HRI workers' compensation claims. Such an assessment could be utilized as a tool to help employers re-evaluate their payment schemes.

This survey design was not adequate to specifically evaluate the impact of acclimatization—a known risk factor for HRI (L. L. Jackson & Rosenberg, 2010). However, it is hypothesized that future research may show that the effects of piece rate pay and lack of acclimatization interact to increase the risk of HRI. Should this association be proved, the Washington State Department of Labor & Industries should consider modifying the Outdoor Heat Exposure rule to include a clause specifically preventing non-acclimatized workers from being paid piece rate.

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