Industrial Health 2013, 51, 34–46

Original Article

Association between Heat Stress and Occupational Injury among Thai Workers: Findings of the Thai Cohort Study

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Received August 24, 2012 and accepted October 24, 2012

Abstract: Global warming will increase heat stress at home and at work. Few studies have addressed the health consequences in tropical low and middle income settings such as Thailand. We report on the association between heat stress and workplace injury among workers enrolled in the large national Thai Cohort Study in 2005 (N=58,495). We used logistic regression to relate heat stress and occupational injury separately for males and females, adjusting for covariate effects of age, income, education, alcohol, smoking, Body Mass Index, job location, job type, sleeping hours, existing illness, and having to work very fast. Nearly 20% of workers experienced occupational heat stress which strongly and significantly associated with occupational injury (adjusted OR 2.12, 95%CI 1.87–2.42 for males and 1.89, 95%CI 1.64–2.18 for females). This study provides evidence connecting heat stress and occupational injury in tropical Thailand and also identifies several factors that increase heat exposure. The findings will be useful for policy makers to consider work-related heat stress problems in tropical Thailand and to develop an occupational health and safety program which is urgently needed given the looming threat of global warming.

Key words: Heat stress, Climate change, Occupational injury, Workers, Thai Cohort Study

Introduction

As global warming proceeds, concern is growing regarding the direct effect of heat stress on human health in many countries[1)]. Recently, studies of heat stress have drawn attention to adverse health effects among workers. The international program "High Occupational Temperature: Health and Productivity Suppression" (HOTHAPS)[2)] has focused on effects of heat exposure on working people and extended its research to many areas, especially tropical developing countries[3–9)].

In low and middle income tropical countries where heat stress is a problem, rapid urbanization and the cash economy may cause workers to do heavy labour for long periods of time under hot and humid conditions, especially those who have low socioeconomic status[10)]. As a result, these workers are exposed to excessive heat and are at risk of heat-related illness and increased occupational injury[11)].

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Possible consequences of excessive heat stress include an increase in the likelihood of occupational injury due to fainting, confusion, poor concentration, and psychological distress, resulting in reduced protection and unsafe working conditions. A relationship between heat stress and injury occurrence has been reported several times over the last 35 yr[11–14]. However these studies were conducted in developed non-tropical countries; this leaves unanswered questions about the effect of heat stress on occupational injury in tropical developing countries where temperatures and humidity are already high. In the future, occupational injury risk in all countries could increase as a result of global warming.

Recent reviews have highlighted global warming and health impacts in tropical areas[2, 15]. In Thailand, hot and humid conditions, especially during the hot season (March to June), can be detrimental to population health. The average temperature in Thailand has already increased 0.74°C over the last century[16]. Increasing heat stress is anticipated as Thailand urbanizes, because of the urban heat island effect and progressive global warming[17].

A recent study of workplace occupational heat stress in Thailand by Langkulsen *et al.*[18] revealed a very serious problem that they classified as "extreme caution" or "danger" in a wide array of work settings. Other studies found that occupational heat stress in Thailand can lead to increased risks of kidney disease and psychological distress[7, 9]. So heat stress is already a public health concern in Thailand and current warming trends are expected to exacerbate the problem due to further increases in air temperatures[19]. However, information on occupational injury related to heat stress in Thailand is still quite limited. As high humidity and hot weather is routine in Thailand, studies on occupational injury almost always overlook heat stress as a contributing factor.

Occupational injury is an important health issue for workers in Thailand[20]. Occupational injury and disease data are recorded primarily through the Workmen's Compensation Fund (WCF) in order to provide cash benefits and medical care to insured workers who suffer workplace injury[21]. In 2008, more than 176,000 cases of occupational injury were reported; 613 cases were fatal and over 45,700 cases reported more than three days absence from work. However, these injury records cover only formal employment which accounts for approximately a third of the Thai workforce[22]. The reports do not capture events at informal work settings, including agricultural work in which heat-related injury is of particular concern due to physically demanding tasks in hot and humid weather[23].

To address the knowledge gap regarding work injury in Thailand, we used the baseline data of a large national adult cohort to examine the epidemiological association between heat stress and injury in the Thai workplace. We identify potential risk factors for heat stress at work. This study will be useful for policy makers considering occupational health and safety program. Such programs are needed to mitigate effects of heat stress at work and prepare for global warming.

Methods

Data and study population

The data derive from the baseline measurements of a large national Thai Cohort Study (TCS) that began in 2005 with distance-learning students enrolled at Sukhothai Thammathirat Open University (STOU). This study investigates the health-risk transition now underway among the Thai population and started with a 20-page mailout health questionnaire; details on overall methodology have been reported elsewhere[24]. Overall, 87,134 students aged 15 to 87 yr responded from all areas of Thailand. They represented the adult Thai population well for geographic distribution, income, age and social status[24].

The baseline data included information on health status and on a wide array of socioeconomic characteristics and health behaviours. As well, heat stress at work and occupational injury were recorded. The heat stress and the occupational injury questions were in different sections of the questionnaire so answers on these issues were independent of each other. The distribution and frequency of risk factors associated with non-traffic injuries by locations have been reported in two recent studies using baseline TCS data[25, 26].

The analysis was restricted to cohort members who reported engaging in paid-work in 2005 (N=62,076). We then excluded 3,581 workers (6%) who did not respond to one or more questions relating to covariates that were potential confounders of heat stress-injury effects (see below). The final analysis group included 58,495 workers (Fig. 1).

Measures of heat stress

The information on individual experiences of heat stress in 2005 was derived from the question: "During the last 12 months, how often did you experience high temperatures which make you uncomfortable?"; respondents answered on a four point scale ("often", "sometimes", "rarely", and "never"). For the main analysis of occupational injury, we

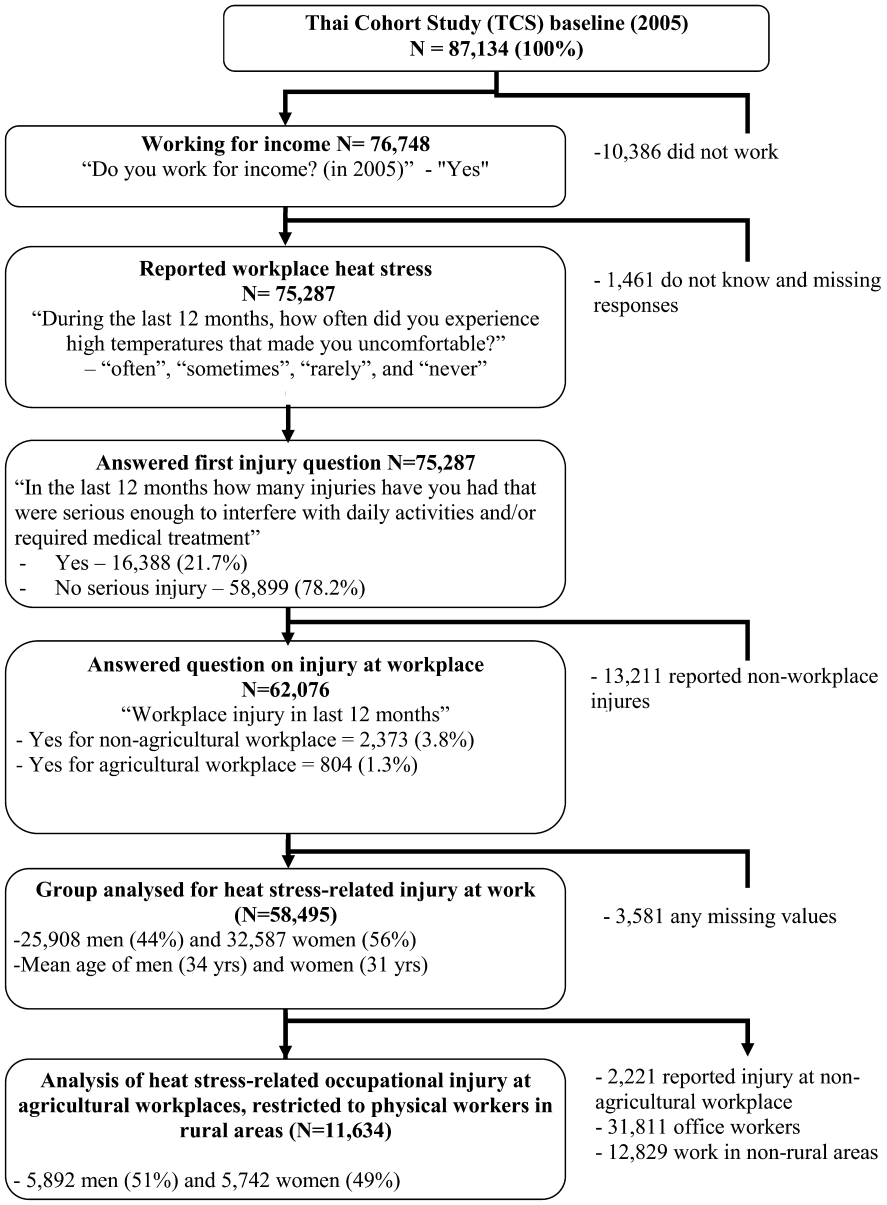

Fig. 1. Selection of the analysed population from the Thai Cohort Study, 2005.

grouped occupational heat stress into three ascending categories: "never" (rarely + never), "sometimes" and "often".

Measures of occupational injury

Information on occupational injury was based on a series of questions as follows. "In the last 12 months how many serious injuries have you had that were enough to interfere with daily activities and/or required medical treatment?" with five answer choices (none, once, twice, three times, and four times or more). For analysis, injury frequency was dichotomised into "yes/no". If injury was experienced more than once, respondents reported details on their most serious injury. Injury events were further characterised by location, identifying occupational injury as follows: "Where were you when you were seriously injured?" (home, road, sports facility, workplace (agricultural), workplace (non-agricultural), or other). For our analyses, "occupational injury" was defined as a serious injury that occurred in the workplace (agricultural or non-agricultural). Finally, for workplace injuries respondents were asked "…how were you seriously injured?" (assault, fall, other blunt force, drowning, bite/sting, gunshot, stab/cut, fire/heat, poisoning, and other injury).

Management of confounding

The covariates that could confound heat-injury effects

were initially selected according to our previous experience with heat stress or injury analyses completed for the cohort[7, 9, 26]. Then, separately for males and females, we investigated the relationship of each covariate to the exposure of interest (heat stress) and (separately) to the outcome of interest (occupational injury). Only covariates with statistically significant chi-square tests for both links (ie. to heat stress and to injury) were included as confounders in final multivariable models. The covariates chosen included age, income in Baht/month (US$ 1=40 Baht in 2005), education level, alcohol consumption, smoking, Body Mass Index (using Asian cut-offs for obesity)[27], job location, job type, sleeping hours per day, existing illness in 2005 (heart or kidney disease, stroke or diabetes), and reports of "having to work very fast".

Data processing and statistical analysis

Data scanning and editing were conducted using Thai Scandevet, SQL, and SPSS software. Data analysis used STATA version 12[28]. The main analysis group included 58,495 workers and all epidemiological estimates were made separately for males (25,908) and females (32,587). First, using logistic regression, we calculated crude (bivariate) odds ratios for workplace heat stress and injury. Subsequently, age as a continuous variable was added to the regression model. Then all factors that could confound workplace heat stress effects on occupational injury (see above) were included as covariates in the multivariable logistic regression analyses. These produced fully adjusted odds ratios, 95% confidence limits, and p-trends showing the dose-response of heat stress effects on occupational injury for males and females.

To test for modification of the heat stress effects, for males and females, we constructed a figure showing covariate-stratified analyses of heat stress-occupational injury relationships. We included all covariates that had statistically significant relationships with both heat stress and occupational injury. These sex-covariate-stratified heat stress-injury odds ratios were adjusted for the mutual effects of all the covariates.

Finally, we examined the association between heat stress and occupational injury among agricultural workers in Thailand. We restricted analysis to the 11,634 cohort members who worked in physical jobs in rural areas having excluded those who reported injury at non-agricultural workplaces.

Ethical considerations

Ethical approval was obtained from Sukhothai Thammathirat Open University Research and Development Institute (protocol 0522/10) and the Australian National University Human Research Ethics Committee (protocol 2004344 and 2009570). Informed, written consent was obtained from all participants.

Results

Characteristics of the cohort

Among the 58,495 Thai baseline (2005) cohort members who worked for income, 25,908 (44%) were male and 32,587 were female (Table 1). Overall, 70% of the cohort was aged between 15–34 yr with the average age of females below that of males (31 vs 34 yr). Half the males and 39% of females had education at high school level; 28% of males and 41% of females had low incomes (≤7,000 Bt/month). Males were more likely to work in rural areas (47% vs 44%) and more likely to have physical jobs (skilled and manual) (50% vs 40%). Among working males, 11% reported that they were regular alcohol drinkers and 20% were current smokers, which was much higher than females (only 0.6% of females reported being regular drinkers and 0.9% reported being current smokers). Males were more likely to be obese than females (24% vs 10%). On average, 12% of workers slept less than 6 h per night and 52% often had to work very fast.

Heat stress at work and occupational injury

Overall, 18% (N=10,784) of the analysed group of 58,495 workers reported that they often experienced uncomfortably high temperatures at work (Table 2). This occurred more often among males than females (22% vs 16%). Females reported never/rarely experiencing heat stress at work more frequently than males (56% vs 44%). Further analyses for heat-related injury at work are done separately for males and females.

Serious injury at work over the previous year was reported by 5% of the whole cohort in 2005 (Table 2). It was higher among males than females (7% vs 4%). The type of occupational injury was heterogeneous but the most common categories were "blunt force" (24%), "stab-cut" (21%), "fall" (18%), and "other" (29%); females were more likely to fall and males were more likely to experience stab-cut or blunt force injury (Table 2).

Association of cohort attributes with workplace heat stress

Figure 2 summarises the association of cohort covariates with heat stress, the exposure of interest, for male and female workers. The crude (bivariate) age association with

Table 1. Socioeconomic status, health behaviour, and other characteristics in a national cohort of 58,495 workers in Thailand

Cohort attributes	Men		Women		Total	
	N	%	N	%	N	%
Total	25,908	44.3	32,587	55.7	58,495	100.0
Age group (yr)						
Less than 35	16,199	62.5	24,771	76.0	40,970	70.0
≥35	9709	37.5	7816	24.0	17,525	30.0
Education						
University	6,349	24.5	9,034	27.7	15,383	26.3
Diploma	6,369	24.6	10,830	33.2	17,199	29.4
High school	13,190	50.9	12,723	39.0	25,913	44.3
Personal income (Baht/month)[a]						
20,001+	4,020	15.5	3,012	9.2	7,032	12.0
10,001–20,000	8,231	31.8	7,779	23.9	16,010	27.4
7,001–10,000	6,422	24.8	8,615	26.4	15,037	25.7
≤7,000	7,235	27.9	13,181	40.5	20,416	34.9
Alcohol consumption						
Never	2,493	9.6	12,809	39.3	15,302	26.2
Stopped/Occasional drinker	20,688	79.9	19,571	60.1	40,259	68.8
Regular drinker	2,727	10.5	207	0.6	2,934	5.0
Smoking						
Never smoked	12,993	50.2	31,140	95.6	44,133	75.5
Ex-smoker	7,745	29.9	1,149	3.5	8,894	15.2
Current smoker	5,170	20.0	298	0.9	5,468	9.4
BMI in 2005						
Normal weight (18.5 to <23)	12,565	48.5	19,497	59.8	32,062	54.8
Underweight (<18.5)	1,375	5.3	6,617	20.3	7,992	13.7
Overweight (23 to <25)	5,856	22.6	3,196	9.8	9,052	15.5
Obese (≥25)	6,112	23.6	3,277	10.1	9,389	16.1
Job location						
Bangkok	3,905	15.1	6,543	20.1	10,448	17.9
Urban	9,859	38.1	11,847	36.4	21,706	37.1
Rural	12,144	46.9	14,197	43.6	26,341	45.0
Job type						
Office job	13,097	50.6	19,698	60.5	32,795	56.1
Physical job	12,811	49.5	12,889	39.6	25,700	43.9
Sleeping hours per day						
6–8 hr	20,013	77.3	24,574	75.4	44,587	76.2
>8 hr	2,829	10.9	3,879	11.9	6,708	11.5
<6 hr	3,066	11.8	4,134	12.7	7,200	12.3
Existing illness[b]						
No other disease	24,854	95.9	31,529	96.7	56,383	96.4
have existing illness	1,054	4.1	1,058	3.3	2,112	3.6
Have to work very fast						
Rarely/never	1,946	7.5	2,070	6.4	4016	6.9
Sometime	11,301	43.6	12,802	39.3	24103	41.2
Often	12,661	48.9	17,715	54.4	30376	51.9

[a]US$ 1 = 40 Baht in 2005, [b]Existing illness in 2005 = people report doctor-diagnosed heart or kidney disease, stroke or diabetes.

Table 2. Reported heat stress at work and occupational injury in a national cohort of 58,495 workers in Thailand

Heat stress and occupational injury	Males		Females		Total	
	N	%	N	%	N	%
Total	25,908	44.3	32,587	55.7	58,495	100.0
Heat stress						
Rarely /Never	11,260	43.5	18,125	55.6	29,385	50.2
Sometimes	8,899	34.4	9,427	28.9	18,326	31.3
Often	5,749	22.2	5,035	15.5	10,784	18.4
Serious injury at work						
No serious injury	24,236	93.6	31,299	96.1	55,535	94.9
Occupational injury	1,672	6.5	1,288	4	2,960	5.1
Type of occupational injury						
Other blunt force	400	25.5	262	21.2	662	23.6
Stab-cut	371	23.7	215	17.4	586	20.9
Fall (not pushed)	228	14.6	271	21.9	499	17.8
Bite-sting (animal, insect)	110	7.0	105	8.5	215	7.7
Road traffic injury	141	8.4	73	5.7	214	7.2
Fire-heat	59	3.8	43	3.5	102	3.6
Poisoning	52	3.3	32	2.6	84	3.0
Assault (punch, push or kick)	33	2.1	9	0.7	42	1.5
Drowning	5	0.3	5	0.4	10	0.4
Gun shot	5	0.3	2	0.2	7	0.3
Other injury	405	25.9	402	32.5	807	28.8

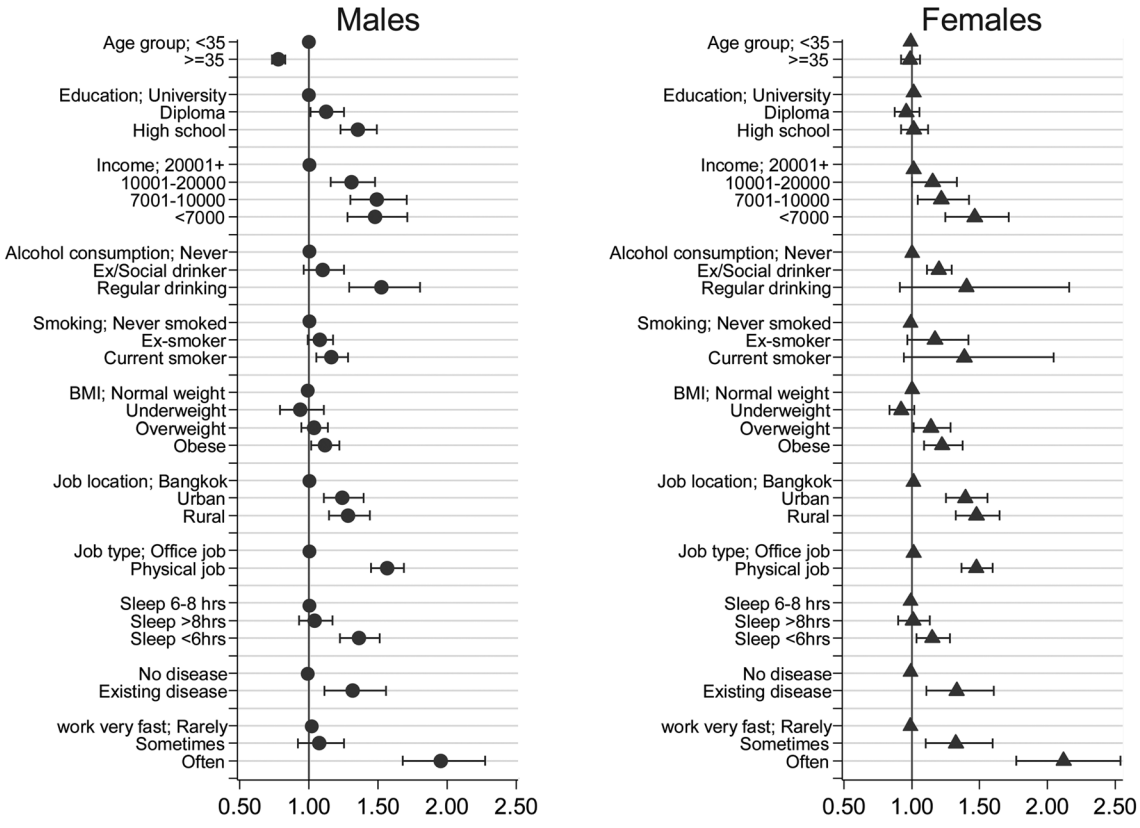

Fig. 2. Association of cohort covariates with heat stress[a].

[a]Workplace heat stress as dependent variable (often/not often); age group ORs (95% CI) not adjusted; all other covariate ORs mutually adjusted (with age included as a continuous variable).

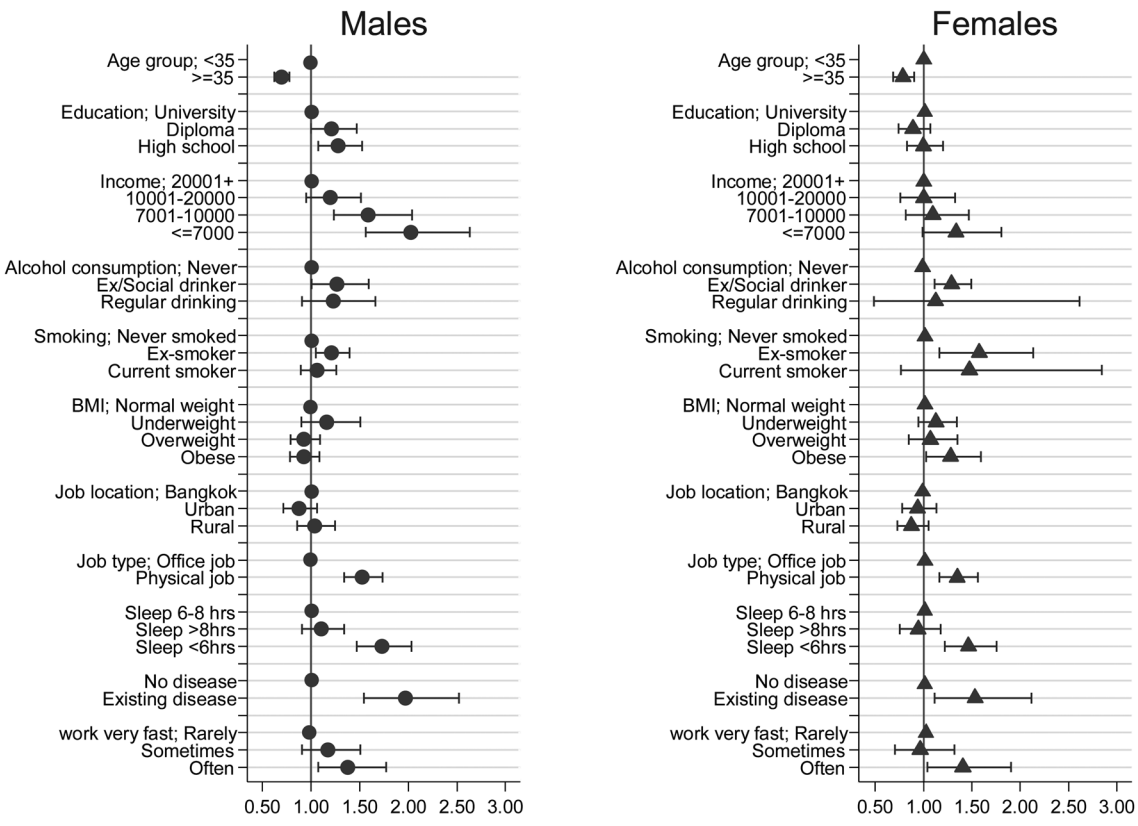

Fig. 3. Association of cohort covariates with occupational injury[a].

[a]Occupational injury as dependent variable (yes/no); age group ORs (95% CI) not adjusted; for all other covariate ORs mutually adjusted (with age included as a continuous variable).

heat stress is shown with age divided into two groups; all the other variables tested for their association with heat stress are adjusted for age as a continuous variable and mutually adjusted for other covariates. For both sexes, all covariates significantly associated with occupational heat stress (except age group and education level in females). Occupational heat stress was notably higher for those with lower income, regular drinking, current smoking, obesity, sleeping less than six hours per day, having "existing illness", and often "having to work very fast". Workers in physical jobs had much more heat stress at work than did office workers ($p<0.001$). Those who worked in rural areas more frequently reported heat stress at work than workers in urban area or Bangkok ($p<0.001$).

Association of cohort attributes with occupational injury

The odds of occupational injury reduced significantly with age for both sexes ($p<0.001$) (Fig. 3). Risks of occupational injury were higher among those with low income, working in physical jobs, sleeping less than 6 h per day, having "existing illness", and often "having to work very fast". Most of these associations were significant and the pattern for males and females were similar; however, income and education effects were more extreme for males.

Association of heat stress and occupational injury by age, income and job type

Overall, the association of heat stress with occupational injury is worse for males than females. It was especially notable for younger workers aged less than 35 yr (Fig. 4). Among males less than 35 yr old (Fig. 4), with low income (≤7,000 Bt/month) (Fig. 5), and with physical jobs (Fig. 6) the proportion reporting injury over the previous 12 months exceeded 10%.

Effects of heat stress on occupational injury

Occupational injury was reported by 10% of males who were often exposed to workplace heat stress compared to 4% who were never exposed. For females, occupational injury affected 7% who were often exposed to heat stress compared to 3% who were never exposed (Table 3). For both males and females the crude ORs linking heat stress

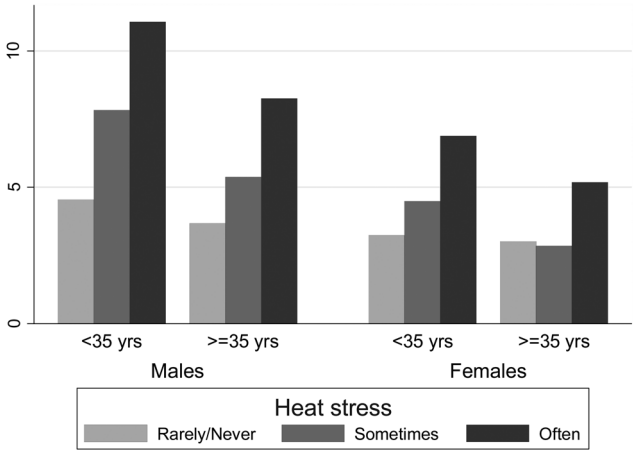

Fig. 4. Occupational injury (%)* by heat stress, sex and age.
*Proportion of Thai workers reporting injury over previous 12 months (see methods).

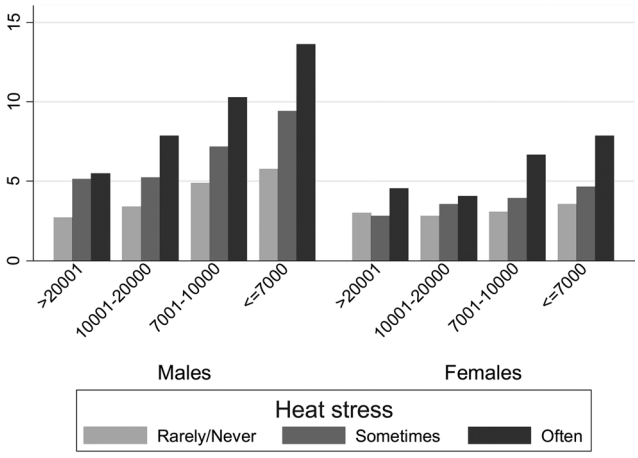

Fig. 5. Occupational injury (%)* by heat stress, sex and income.
*Proportion of Thai workers reporting injury over previous 12 months (see methods).

and occupational injury showed a strong association (OR > 2) and a notable dose response. Age group adjustment had little effect. The fully adjusted ORs derived from models that included continuous age (yrs), income, education, job location, smoking, alcohol drinking, BMI, job location, job type, sleeping hours, existing disease, and having to work very fast. The covariate-adjusted dose-response relationships of heat stress and occupational injury remained strong and significant for both sexes (adjusted OR for heat stress "often" 2.12 (males) and 1.90 (females), p-trend<0.001).

Modification of the heat stress-injury effects was investigated using stratified analyses for each of the significant covariates (Fig. 7). For each covariate, heat stress-injury OR analyses were restricted in strata corresponding to each value of the covariate. For most of these covariates, there was little evidence that their values modified the heat stress-injury ORs. But, for both sexes, heat stress-injury effects were modified by a few covariates: the ORs substantially increased for low education level, regular drinking, short sleeping hours, and having to work fast.

Effects of heat stress on occupational injury in agricultural workplaces

Finally, we explored effects of heat stress on occupational injury that occurred in the agriculture workplace by restricting analysis to those respondents who worked in rural areas with physical jobs, excluding those who reported injury at non-agricultural workplaces. Overall, 23% of physical workers in rural areas often experienced heat stress − 27% for males and 19% for females (data not shown). Heat stress in this restricted rural physical jobs group is higher than among the 58,459 working cohort members, for whom the overall rate was 18% (Table 2).

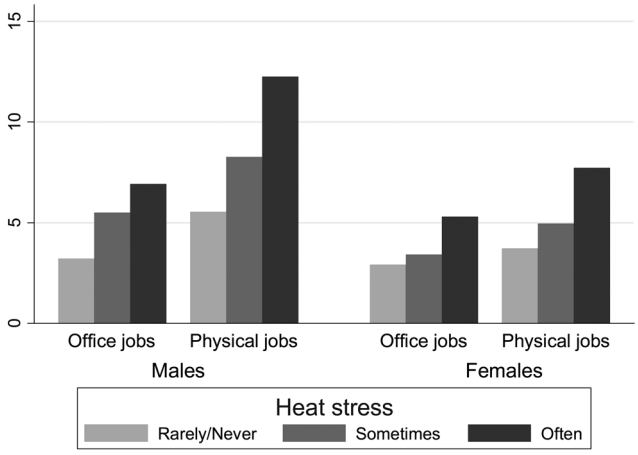

Fig. 6. Occupational injury (%)* by heat stress, sex and job type.
*Proportion of Thai workers reporting injury over previous 12 months (see methods).

The pattern linking heat stress and occupational injury at agricultural workplaces in Table 4 was similar to that shown for workers in Table 3. Male physical workers reported 228 occupational injuries at agricultural workplaces; these injuries affected 6% of those often exposed to heat stress compared to 3% of those unexposed (adjusted OR=1.99). Female physical workers reported 84 occupational injuries at agricultural workplaces; these injuries affected 3% of those often heat stressed at work compared to 1% of the unexposed (adjusted OR=2.58).

Table 3. Associations between heat stress and occupational injury among male and female workers (N=58,495)

	Heat stress 2005	Occupational Injury		Odds Ratios (ORs)				
		N	%	Crude	Age adj.[a]	Adj.[b]	(95% CI)	p-trend
Male	N = 25,908	1,672	6.5					
	Never/Rarely	473	4.2	1	1	1		<0.001
	Sometimes	616	6.9	1.70***	1.68***	1.54***	(1.36–1.74)	
	Often	583	10.1	2.57***	2.51***	2.12***	(1.87–2.42)	
Females	N = 32,587	1,288	4					
	Never/Rarely	578	3.2	1	1	1		<0.001
	Sometimes	384	4.1	1.29***	1.30***	1.24***	(1.08–1.42)	
	Often	326	6.5	2.10***	2.11***	1.90***	(1.64–2.18)	

*p-value<0.05, **p-value<0.01, ***p-value<0.001.

[a]Associations of heat stress and occupational injury expressed as ORs adjusted for age (<35 yr, ≥35 yr).

[b]Associations of heat stress and occupational injury expressed as ORs adjusted for age (yr), alcohol, smoking, BMI, income, education, job type, job location, sleeping hours, having to work very fast, and existing illness (see Methods).

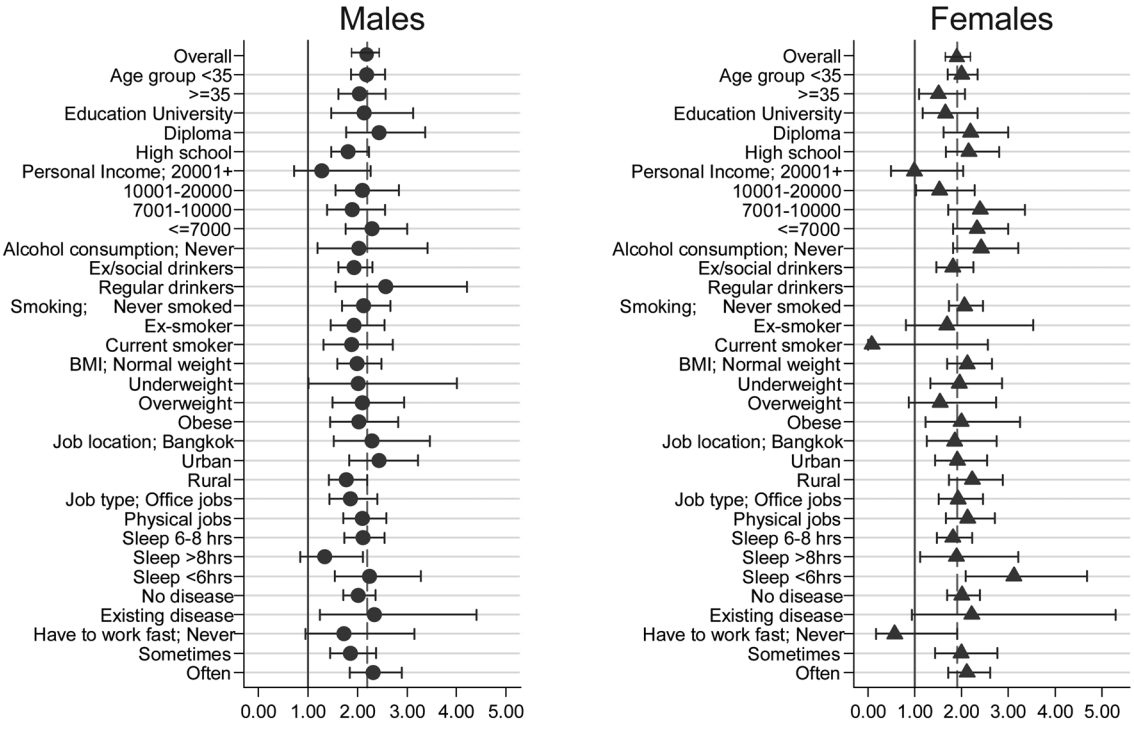

Fig. 7. Stratified analyses of the association between heat stress and occupational injury for males and females[a].

[a]Analyses of heat stress-injury odds ratios (ORs) are repeated for each value of each covariate; all these stratified ORs (95% CI) are mutually adjusted for the influence of all other covariates.

Discussion

Principal findings

Heat stress at work in Thailand has a strong and significant association with occupational injury. This is important because occupational heat stress affected nearly 20% of Thai workers in the national cohort. These findings add to a limited literature on the association between heat stress and occupational injury of Thai workers. The association between heat stress at work and occupational injury remained substantial and statistically significant after accounting for the effects of age, income, education, alcohol, smoking, Body Mass Index, job location, job type, sleeping hours per day, existing illness in 2005, and having to work very fast. For rural physical workers at agriculture workplaces we found a similar association between heat stress and occupational injury.

Table 4. Associations between heat stress and occupational injury at agricultural workplaces among male and female workers in rural areas with physical jobs (N=11,634)

	Heat stress 2005	Occupational injury		ORs				
		N	%	Crude	Age adj.[a]	Adj.[b]	(95%CI)	*p*-trend
Males	N=5,892	228	3.9					
	Never/Rarely	59	2.8	1	1	1		<0.001
	Sometimes	81	3.7	1.35	1.35	1.31	(0.93–1.85)	
	Often	88	5.6	2.09***	2.08***	1.99***	(1.41–2.81)	
Females	N=5,742	84	1.5					
	Never/Rarely	25	0.9	1	1	1		0.001
	Sometimes	31	1.6	1.78*	1.74*	1.64	(0.96–2.80)	
	Often	28	2.5	2.80***	2.74***	2.58***	(1.49–4.47)	

*p-value<0.05, **p-value<0.01, ***p-value<0.001.

[a]Associations of heat stress and occupational injury expressed as ORs adjusted for age (<35 yr, ≥35 yr)

[b]Associations of heat stress and occupational injury expressed as ORs adjusted for age (yrs), alcohol, smoking, BMI, income, education, job type, job location, sleeping hours, having to work very fast, and existing illness (see Methods).

Strengths and weakness of the study

The main advantage of this study is that it was based on a large national cohort of 58,495 workers who represent well working age Thais for geographic location, demographic attributes and socioeconomic status. Cohort members are better educated than average Thais of the same age and sex[24]. Because of their education advantage, workplace heat stress exposure in the cohort may underrepresent the magnitude of the problem in the general population. Although this impacts the reported exposure (which was already substantial with 20% of the Thai cohort workers experiencing occupational heat stress) it is unlikely to affect the reported associations between exposures and outcomes.

The cohort data have a wide range of values for variables of interest, revealing the relationship between heat stress and occupational injury. We strengthened our results by the restricted analysis of 11,634 workers with physical jobs in rural areas, excluding those reporting injury in the non-agricultural workplaces. The patterns of the association between heat stress and occupational injury were similar to the overall analysis of 58,459 cohort workers.

A limitation of this study could have arisen if people had experienced their heat stress during a hot period and their injury during a cold period. If this happened the frequency of injury and the frequency of heat stress would be unrelated. However, there is no really cold period in most of Thailand and our data showed a consistent association between reported heat stress and reported injury over the previous 12 months. But we cannot prove that the injury occurred at the same time as the heat stress and such a linked measurement was not a feasible part our study design. We can prove the association we found is unlikely to be due to chance (p<0.001) and this fits well with an epidemiological model linking heat stress to increased injury risk. The heat-injury model is supported by a dose response whereby more heat stress associated with increased odds of injury.

The main disadvantage of this study is that it could not directly establish that the occupational injury arose as a result of heat stress. There are some difficulties in interpreting causality between heat stress and occupational injury given that we cannot formally be sure that heat stress preceded occupational injury. However, it is not likely that heat stress resulted from injury as there is no obvious mechanism for such an effect.

Another problem is the unknown source or nature of the heat stress at work as this was not reported in the cohort data. Furthermore, we were not able to make direct measurements of work environments or occupational injury, so we classify this study as preliminary in nature.

Compare with other studies

Occupational heat stress is a problem in Thailand, especially in agriculture workplaces[18, 29]. Our study also found that Thais often work under heat stress, especially those with physical jobs in rural areas. The proportion of workers in both sexes who reported occupational injury declined with age; this may reflect ageing, working experience, and shifting away from work with high risk of injury[30]. The younger age group reported more occupational injury perhaps because of their lower socioeconomic status. They cannot afford to go to a regular university and are more likely to have a job with less safety[14].

As expected from other studies, we found a higher risk of serious occupational injury among males[30, 31]. Another important risk factor significantly associated with occupational injury was low income (≤7,000 Baht/month), already noted with a previous study of the Thai cohort on risk factors associated with injury[26]. As with other studies on occupational injury, we found that the risk of injury related to job type, rural job location[32], and frequency of alcohol consumption[33].

Other TCS studies reported associations between occupational heat stress and adverse health outcomes, including poor self-assessed overall health, psychological distress, and incident kidney disease among Thai workers[7, 9]. This study now adds additional concerns about the effects of heat stress on occupational injury in Thailand.

Significance of this study

The findings support the reported by Kjellstrom *et al.*[2] that occupational heat stress increases the risk of serious injury and ill-health among workers who are exposed to hot and humid work environments, especially in low income-tropical countries[4]. The combination of hot weather and high humidity together with workers' physical exertion and dehydration can cause potentially heat-related illness or heat exhaustion (fainting or collapse) which could increase occupational injury and associated costs as well as reduce work performance and productivity.

Moreover, heat-stress related occupational injuries are especially important at present because we can expect that the existing heat stress problem will worsen if global warming continues and workplaces become even more thermally stressful[34]. Given the constrained resources in middle-income Thailand and the lack of effective policy and guidelines on prevention and management of heat stress and occupational injury, our results on occupational injury are of particular concern.

In Thailand, a large proportion of the population is in the working age group. Furthermore, the National Statistical Office reported that 46% of employed Thais were working in the agricultural sector[35]. As already shown in the final analysis of this study, physical workers in rural areas often worked under heat stress.

Thai workers must take safety precautions while working under heat stress and policymakers should develop the interventions to prevent occupational injury, especially during summer for the new young workers. Prevention of heat stress-related injury through education, training and procedures is needed to protect workers in all type of work environments.

Future research

We have used telephone contact to validate the occurrence of heat stress for 82% of a random sample of 135 cohort members who had self-reported heat stress (data not shown). The validation boosts our confidence in the self-reported measurement of heat exposure. We also queried the source of the heat and discovered that it often came from the prevailing external air temperature when working outdoors (48%), from the work process itself (31%), from working indoors without air conditioning (13%), or from working in a hot vehicle (6%). Now direct observations of heat stress and its effects in informative work settings are needed to add information on the physical and biomechanical mechanisms generating heat stress and linking it to injury and other adverse health effects.

Also, we need to investigate heat stress-related injury so we can accurately characterize associated occupational injury. As well, we should investigate heat-related injury in different regions of Thailand because the geography and heat stress are different. For example, in Thailand temperatures vary considerably during the day and night in the North and vary little in the South.

Conclusion

The association between occupational heat stress and occupational injury reported here is a great concern. More information is needed on the nature and source of the heat stress and on the associated injury. Continued urbanisation and global warming will make these trends worse for workers in tropical developing countries like Thailand. Injury interventions in such settings need to include strategies that mitigate occupational heat stress. Also we need to develop and test interventions that reduce the number and severity of occupational injuries in Thailand.

Conflicts of interest

The authors declare that we have no competing interests.

Acknowledgements

This study was supported by the International Collaborative Research Grants Scheme with joint grants from the Wellcome Trust UK (GR071587MA) and the Australian National Health and Medical Research Council (NHMRC 268055), and as a global health grant from the NHMRC (585426). These funding bodies play no role in the prepa-

ration or submission of this manuscript. We thank the Thai Cohort Study team*, the staff at Sukhothai Thammathirat Open University (STOU) who assisted with student contact, and the STOU students who are participating in the cohort study. We also thank Dr Bandit Thinkamrop and his team from Khon Kaen University for guiding us successfully through the complex data processing.

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