January 2012

Relationships of Heat Stress Levels to Heat-Related Disorders and Acute Injury During Deepwater Horizon Cleanup Operations

Michael H. Hiles
University of South Florida, hilesmike@gmail.com

Relationships of Heat Stress Levels to Heat-Related Disorders and Acute Injury During Deepwater Horizon Cleanup Operations

by

Michael Hiles

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Public Health
Department of Environmental and Occupational Health
College of Public Health
University of South Florida

Major Professor: Thomas E. Bernard, Ph.D.
Yehia Y. Hamad, Sc.D.
Steven Mlynarek, Ph.D.

Date of Approval:
July 12, 2012

Keywords: Heat-Related Disorders, Acute Injury,
Heat Stress, Emergency Response

Acknowledgements

First, I would like to thank my wife for her years of patience and support as I further my education. Next, I would like to thank CDC/NIOSH (T42-OH008438) for supporting future Industrial Hygienists by offering ERC scholarships and stipends. Without such economic help it would have been a great deal more difficult to pursue a MSPH in Industrial Hygiene. A debt of gratitude is owed to my major professor, Dr. Thomas E. Bernard, for his continued patience, guidance and expert advice without which this thesis would not have been possible. A thank you is also due to Dr. Skai W. Schwartz for her expertise in statistical analysis. I must also thank BP for the use of their injury and illness database and April Clark, who was instrumental in providing the de-identified database for this study. I would also like to thank the other two members of my thesis committee, Dr. Yehia Y. Hammad and Dr. Steven Mlynarek for their dedication to teaching and commitment toward their students.

The data used to produce this report were provided to the University of South Florida (USF) by BP safety personnel. The opinions expressed in this paper are those of the authors and do not reflect the opinions of CDC/NIOSH or BP.

Table of Contents

List of Tables	ii
List of Figures	iii
List of Abbreviations	iv
Abstract	vi
Introduction	1
Literature Review	4
Methods	9
Results	15
Discussion & Conclusions	20
References	24

List of Tables

Table 1	Database Categories	10
Table 2	Descriptors for Heat-Related and Acute Injury	11
Table 3	Periods of the day with number of hours, the assigned dry bulb temperature and the assumed elevation in globe temperature above dry bulb temperature (ΔTg-d)	13
Table 4	Number of workers and labor-hours by month	14
Table 5	Labor-hours at Each Heat Stress Level	14
Table 6	Number of Incidents By Type and Incident Severity	15
Table 7	Incident Rate (per 200,000 hr)	16
Table 8	Rate Ratios by Heat Stress Level (HSL) by Incident Type and by Incident Severity	17

List of Figures

Figure 1. Rate Ratio for All Incidents by Heat Stress Level with 95% CL 18

Figure 2. Rate Ratio for Heat Related Incidents (Disorders) by Heat Stress Level with 95% CL 18

Figure 3. Rate Ratio for Acute Injuries by Heat Stress Level with 95% CL 19

Figure 4. Rate Ratio for incidents requiring First Aid by Heat Stress Level with 95% CL 19

List of Abbreviations

BLS	Bureau of Labor Statistics
CFOL	Census of Fatal Occupational Injuries
CI	Confidence interval
DAFW	Days away from work
HSL	Heat Stress Level
ICP	Incident command post
kPa	Kilopascal
LCL	Lower Confidence Limit
NIOSH	National Institute for Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
OEL	Occupational Exposure Limit
Pv	Vapor pressure
RR	Rate Ratio
Tdb	Dry bulb temperature
Tdp	Dew point temperature
Tg	Globe temperature
TLV	Threshold Limit Values
Tnwb	Natural wet-bulb temperature
Tpwb	Psychometric wet bulb
UBI	Unsafe Behavior Index
UCL	Upper Confidence Limit
Vair	Average air speed
WBGT	Wet bulb globe temperature
Δ	Change in

Abstract

Outdoor workers are often subjected to thermal conditions beyond the comfort zone, but to what degree do such conditions affect the health and safety of those workers is still a matter requiring further investigation. The purpose of this study is to examine the relationship between thermal conditions and (1) heat-related disorders and (2) acute injuries using injury and illness data collected during the BP Deepwater Horizon clean-up operations. Over an eleven month period, 5,485 cases were identified as either heat-related or an acute injury (incident type) and further divided by severity. Daily weather data were used to estimate the wet bulb globe temperature (WBGT) based on the time of day. Heat Stress Levels intervals were defined using the estimated WBGT. Labor-hours by month were estimated by the prevailing shift length in the month and the number of workers. The incidents were assigned a Heat Stress Level and the number of labor-hours by heat stress level were determined. The next step was to calculate the incident rate ratio by Heat Stress Level against the baseline of thermal comfort. The results indicated that the rate ratios for heat-related disorders and acute injury increased for thermal conditions from 24ºC-WBGT to 30ºC-WBGT. There was a further significant increase in rate ratio for heat-related injury above 33 °C-WBGT. It was notable that the incident rates for both heat-related

disorders and acute injuries increased at thermal conditions generally considered to be below the occupational exposure limit (OEL) at 30 ºC-WBGT. The rate of heat-related disorders increased substantially above the occupational exposure limit.

Introduction

Heat waves are not a new phenomenon in the United States. In fact, in 1936 around 5000 deaths were associated with record high temperatures.[1] More recently, in 1980, there were 1,700 deaths in United States relating to temperature conditions that ranged from 101 °F to 112 °F.[2, 3] The populations hardest hit by these elevated thermal conditions were "those of low socioeconomic status, the aged, and those engaged in heavy physical labor".[2] Numerous epidemiological studies have shown that the elderly and the very young tend to be the most sensitive to heat, while those men and women of working age are far less susceptible. However, occupational exertion during periods of elevated thermal conditions has taken its toll on the apparently healthy and physically fit working populations as well.

Heat exposure within occupational environments is a problem for the health and safety of workers. Individuals working in outdoor environments especially during the summer months have to contend with temperatures that can range well above 100 °F, but such temperatures are not limited to outdoor work. Environments that cannot be effectively regulated by a cooling system due to the nature of the work performed, such as aluminum, iron, glass, and steel manufacturing also pose ongoing health risks.[4] Protective clothing can also add to such risks.[5]

In the United States from 2008 through 2010, 99 deaths related to environmental heat stress were recorded by the US Bureau of Labor Statistics (BLS) Census of Fatal Occupational Injuries (CFOI).[6] In addition, a total of 6,920 nonfatal occupational injuries and illnesses involving days away from work were reported to be a result of exposure to environmental heat.[6] Given that these numbers constitute economic and noneconomic costs to industry, individuals, and families it is vital that attention be given to the dangers associated with heat-related illnesses and the risks of acute injury and death relating to environmental conditions. In the nearly fifteen year period spanning 1992 to 2006 there were a total of 423 deaths caused by exposure to environmental heat.[7] Of this number 68 were individuals working in the agricultural industry where exposure to environmental heat is common. Seventy-eight percent of the agricultural workers who died were between the ages of 20 and 54.[7] Heat injuries do not require extremely elevated outdoor temperatures especially when physical excursion is involved.[8] It has been well documented that individuals working in outdoor environments such as on a farm, or on a construction site in hot and humid weather face the serious threat of an acute heat-related injury.[9] However, there is growing evidence that supports the fact that before such heat-related illnesses occur, extremes in thermal conditions beyond those desired by most individuals can lead to decrements in safety-related behaviors within the work environment.[10]

With this view in mind an opportunity to further document the association between elevated thermal conditions and increased accidents presented itself in the aftermath of the BP Deepwater Horizon oil platform explosion in the Gulf of Mexico in the spring of 2010. The clean-up efforts that took place subjected tens of thousands of workers to outdoor work all along the gulf coast.[11]

The purpose of this study was to examine if an increase in heat exposure results in increases in the heat-related disorders and in an increase in the incidences of acute injuries.

Literature Review

Elevated environmental thermal conditions pose physiological dangers to workers, but what happens to those workers prior to reaching those physiological limits has been the focus of increasing study. What has been found is that as thermal conditions increase there is a corresponding increase in unsafe behavior and accidents.

Ramsey's work with the unsafe behavior index (UBI) in 1983 found a "U"-shaped curve representative of the prevalence of unsafe behaviors in relation to wet bulb globe temperature (WBGT). He also found that minimum UBI values occurred within the range of 17º to 23ºC WBGT within the comfort range for light workload.[10] As ambient temperatures rose above or dropped below this "preferred temperature zone" the UBI increased. Ramsey also found that higher metabolic workload levels corresponded to increases in the UBI.[10] In his later review (1995) of 160 studies of perceptual motor performance and the hot work environment, Ramsey found that tasks requiring perceptual motor skills beyond mere mental or basic tasks showed "statistically significant decrements" occurring in the range of 30 - 33 ºC WBGT.[12]

Similar to Ramsey's inverted "U" shaped UBI is Hancock's maximal adaptability model. Using this model Hancock described how under normal conditions individuals can perform at their optimal level within their comfort zone; however, as environmental stressors increase, an individual's "attentional resources" will be tapped and progressively diminished in relation to their primary work task.[13] As the environmental stress continues to increase an individual's ability to devote their full attention to their task decreases, which in turn can lead to unsafe behavior. Hancock called this zone of cognitive depletion the Psychological Zone of Maximal Adaptability.[13] He found that continued stress within this psychological zone leads to a physiological shift out of homeostasis and toward a potential acute heat-stress injury. Hancock and Vasmatzidis pointed out that these cognitive depletions begin with only minor elevations in deep body temperature. They also found that as the cognitive demands of a given task increase there is less of a shift in deep body temperature needed to impair performance.[14] Hancock's psychological model is further supported by findings of The National Institute for Occupational Safety and Health (NIOSH).[15]

NIOSH reported that as the body works to maintain homeostasis, it sends blood out to the body's surfaces to be cooled with the help of evaporation. When this occurs there can be relatively less blood traveling to "the active muscles, the brain, and other internal organs; as a result strength declines and fatigue occurs sooner than it would otherwise."[15] Increased sweating can lead to slippery hands, safety goggles may fog up and reduce visibility, and dizziness may hamper job performance. As further indicated by NIOSH in its 1986 publication, concerning safety problems:

Aside from these obvious dangers, the frequency of accidents, in general appears to be higher in hot environments than in more moderate environmental conditions. One reason is that working in a hot environment lowers the mental alertness and physical performance of an individual. Increased body temperature and physical discomfort promote irritability, anger, and other emotional states which sometimes cause workers to overlook safety procedures or to divert attention from hazardous tasks.[15]

A number of studies have also shown that prior to the development of diagnosable heat-related disorder an individual's task performance and productivity can be affected. Early signs of heat stress can include thirst, fatigue, and decrements in vigilance, visual tracking, response time, short-term memory, and auditory discrimination.[14, 16, 17, 18]

In fact, studies dating back nearly 95 years found that task performance and productivity were inversely related to thermal conditions and that the number of accidents increased with increases in thermal conditions. From 1919 to 1927 H.M. Vernon performed a series of studies in the hot work industries of glass, steel, tinplate and munitions manufacturing as well as coal mining. Results of those studies indicated that when temperatures increased work rate/output declined and accident rates increased. Weston (1922) and Wyatt (1926) found that the same relationship existed in the linen weaving industry.[19]

More recently, in 2003 Chen conducted a study that assessed fatigue among workers in a steel plant. Individuals in two specific areas of the plant were assessed. The WBGT within those areas was 25.4 – 28.7 ºC-WBGT in the steel casting area and 30.0 – 33.2 ºC-WBGT in the electric arc melting area. His study found that workers in the hotter area reported greater “subjective discomfort” or fatigue and had significantly slower response times.[17] In a study on the association of heat stress and helicopter pilot errors, Froom found that on days when the air temperature was greater than 30 ºC, there was an increased frequency of multiple accidents associated with pilot error.[20]

To further complicate matters, low level dehydration may become a key issue if it becomes progressive or cumulative in that it develops over a period of days when the amount of water being replaced is insufficient to restore the body to a state of proper hydration prior to beginning the next day’s work. Such progressive or cumulative dehydration can impair or overwhelm the body’s thermoregulatory system.[8, 21] Individuals involved in strenuous physical activities in hot environments can lose up to 3 liters of water and 3.5 grams of sodium each hour as they sweat.[22] Goprinathan found that with just 2% dehydration there was a significant impairment in mental performance, short-term memory, and visual-motor tracking skills.[23]

The psychological zone of maximal adaptability suggested that there should be an increase in acute injury with increasing levels of heat stress. There was empirical evidence of the injury rate increasing with increasing heat stress as well as an increase in unsafe behaviors. Further, there was evidence that the rate of heat-related disorders increases with heat stress due to the uncompensated physiological demands.

The purpose of this study was to examine if an increase in heat exposure results in increases in the heat-related disorders and in an increase in the incidences of acute injuries. The null hypothesis was that the rate of heat-related disorders and acute injuries does not change with heat stress level.

Methods

To test the hypothesis that increasing levels of thermal stress are associated with increases in incident rates for heat-related disorders and acute injury incidences, a database containing all the recorded injuries and illnesses from May 2010 through March 2011 during the Deepwater Horizon clean-up efforts was provided by BP. The database was comprised of the injury and illness that was believed to be work-related. It included incidents that occurred to BP employees, BP contracted workers, federal/state/local responders, and volunteers. There may be some local (parish) workers involved in response efforts who did not fall under the supervision of the Unified Area Command, and thus would not be included in this database. This method of employer-generated data collection is standard occupational safety and health practice. It should be noted that because the data used for this report were collected by BP, USF cannot independently verify the accuracy and completeness of the database. The database contained 20,033 de-identified cases of recorded injury and illness collected for this study. Major categories are provided in Table 1.

Table 1: Database Categories

Original Database (N = 20,033)	USF Database (N = 5,485)

• Date and time of incident
• Date and time incident was recorded
• Incident Command Post (ICP)
• Incident location
• City and state of incident
• Age
• Job type
• Chief complaint (and secondary complaints, if any)
• Type of injury by code (with secondary codes, if any)
• Body location of injury
• Disposition
• Medical outcome
• OSHA Classification (include visits, first aid and recordables)
	Data Converted Directly from BP Database
	• Assigned date and time of incident
	• Incident Command Post (ICP)
	    ○ Mobile (1)
	    ○ Houma plus Houston (2)
	• Age
	• OSHA Classification
	    ○ First Aid
	    ○ Medical Treatment
	    ○ Restricted Duty
	    ○ Days Away from Work (DAFW)
	
	Additional Data for the Study
	• Incident Type
	    ○ Heat-Related
	    ○ Acute Injury
	• Estimated WBGT
	• Assigned Heat Stress Level (HSL)
	    ○ 0: < 24 °C-WBGT
	    ○ 1: 24 to <27 °C-WBGT
	    ○ 2: 27 to <30 °C-WBGT
	    ○ 3: 30 to <33 °C-WBGT
	    ○ >3: ≥ 33 °C-WBGT

The first requirement for inclusion in the analysis database was that the injuries or illnesses recorded be designated by BP as an OSHA Classification of First Aid or an OSHA-recordable category. This requirement reduced the analysis database to about 7,000 records of occupationally-related injury or illness. The injury complaints and codes for these records were then examined for any primary or secondary complaint that was broadly associated with heat exposure, and these were classified as Heat-Related disorders. The remaining records were reviewed for accidents or mishaps that involved acute injury or acute muscular skeletal disorders; and these were designated as acute injuries.

The breakdown of the descriptions used for heat-related disorders and acute injuries appears in Table 2. Records, which had specific causes such as chemical exposures, insect bites, systemic diseases, chronic disorders, and infections, were removed from the database. The final number of included records after the described reduction was 5,485.

Table 2: Descriptors for Heat-Related and Acute Injury

Heat-Related Descriptors	Acute Injuries Descriptors
• Heat stroke or (Sunstroke) • Loss of consciousness (fainting) due to heat • Heat Fatigue (exhaustion) • Unspecified effects of environmental conditions • Malaise & fatigue • Heat Rash / disorders of the sweat glands Dizziness • Unspecified tachycardia (rapid heartbeat) • Headache (non-chemical induced) • Nausea & vomiting (non-chemical induced)	• Dislocations & fractures • Cuts, lacerations • Punctures except bites • Open wounds unspecified • Abrasions, scratches • Blisters • Bruises, contusions, hematomas • Foreign bodies (splinters, chips) • Surface wounds, unspecified • Chemical burn • Electrical burns • Heat burns & scalds • Burns unspecified • Concussion • Intracranial injuries unspecified • Drowning • Electrocutions, electric shock • Dermatitis (rash) • Sunburn • Traumatic injuries to bones, nerves, spinal cord unspecified • Sprains, strains, tears • Traumatic injuries to muscles, tendons, ligaments, joints, etc., unspecified • Back pain, back hurt • Soreness or pain, except the back

For records with missing dates and times for the incident, the date and time of the record was used. For records that lacked a specific time for the incident or the record, the time for the incident was left blank (missing).

Most of the records were associated with the Mobile and Houma Incident Command Centers (ICPs). The Mobile ICP included base locations in Alabama, Mississippi, and Florida. Houma included Louisiana and Texas.

To estimate WBGT for the records, daily weather data from May 2010 through April 2011 for New Orleans, which was assigned to Houma and Houston ICP, and for Mobile for the Mobile ICP were obtained from Weather Source, a company that specializes in historical and real-time digital weather data.[26] The data used from this weather database included the maximum, minimum and average dry bulb (air) temperature (Tdb), the average dew point temperature (Tdp) and the average air speed (Vair).

The day was divided into three periods as described in Table 3. Under the "Minimum" period only five hours were assigned to account for the reduced work schedule during this period. For each period, the value for Tdb was taken as the value described in the table. The water vapor pressure (Pv [kPa]) was computed from the average dew point (°C).[27]

$$Pv = 0.1 \times 10^{(18.956-4030.18/(Tdp+235))}$$

The psychrometric wet bulb (Tpwb [°C]) was estimated from Tdb and Pv.[28]

$$Tpwb = 0.376+5.79\ Pv+(0.388-0.0465\ Pv)\ Tdb$$

The natural wet bulb temperature (Tnwb) was taken as 1 °C above the Tpwb. Estimating the globe temperature (Tg) as an elevation above the dry bulb as indicated in Table 3 then allows an estimate of the WBGT for each day and period of the day as

$$WBGT = 0.7\ Tnwb + 0.3\ Tg$$

Table 3. Periods of the day with assigned number of hours, the assigned dry bulb temperature and the assumed elevation in globe temperature above dry bulb temperature (ΔTg-d)

Period	Hours of the Day	Assigned Hours	Assigned Tdb	ΔTg-d [°C]
Max	10 AM to 4 PM	6	Maximum	8
Mean	4 PM to 8 PM	4	Average	4
Min	Midnight to 10 AM and 8 PM to Midnight	5*	Minimum	0

*Individuals did not work around the clock. The assigned hours covers the estimated hours worked during this period.

Heat Stress Level (HSL) was based on the estimated WBGT. HSL 0 was the baseline reference and included all WBGTs < 24ºC-WBGT; HSL 1 ranged from 24 to 26.9 ºC-WBGT; HSL 2 ranged from 27 to 29.9 ºC-WBGT; HSL 3 ranged from 30 to 32.9 ºC-WBGT; and HSL >3 included all temperatures ≥ 33 ºC-WBGT. Based on the day and time, the HSL was assigned to each record. In the absence of a time, the Mean Period was assumed.

For both locations and using the periods, the hours assigned to the periods and the associated HSL for each day, the number of hours in each month at each HSL was determined.

The next step was to estimate the labor hours each month. Table 4 provides the number of workers reported by BP for the given month and the total hours based on a 6-day workweek at 12 hours per day from May through December 2010 and 10 hours per day from January through April. As an approximation, half the hours were assigned to Mobile and half to Houma. The number of labor-hours at each Heat Stress Level was in proportion to the fraction of time by location and month in each level. The total labor-hours by HSL is provided in Table 5.

Table 4. Number of workers and labor-hours by month

Month	Workers	Labor-Hrs
May	16,979	1222464
Jun	26,048	1875456
July	37,348	2689042
Aug	22,605	1627524
Sept	24,301	1749696
Oct	16,292	1173024
Nov	6,612	476064
Dec	5,428	390816
Jan	3,795	227700
Feb	3,801	228060
March	2,444	146640
April	2,000	120000

Table 5: Labor-Hours at Each Heat Stress Level

Heat Stress Level	Labor-Hours
0	1388488
1	2074500
2	2729457
3	2573771
>3	3160270

Results

To begin to examine the relationship between thermal conditions and heat-related disorders and acute injuries it was necessary to break those incidents down by type and severity. Table 6 summarizes that break down. The incidents in Table 6 were first broken into acute injury and heat-related disorder incident types, which were then further divided by the HSL. Included within the same table were the incidents broken down into OSHA severity classification.

Table 6: Number of Incidents By Type and Incident Severity

Heat Stress Level	All	First Aid	Medical Treatment	Restricted Duty	Days Away From Work
Acute Injury					
0	187	121	48	8	10
1	432	358	43	8	23
2	834	674	100	15	45
3	642	530	78	6	28
>3	817	685	83	13	36
Heat-Related					
0	28	18	10	0	0
1	261	219	32	1	9
2	542	472	52	1	17
3	524	456	58	0	10
>3	1218	1069	117	1	31
All Incidents					
0	215	139	58	8	10
1	693	577	75	9	32
2	1376	1146	152	16	62
3	1166	986	136	6	38
>3	2035	1754	200	14	67

Labor–hours (see Table 5) were then used to calculate the incident rates by first multiplying the number of incidents in each severity class by 200,000 hour (100 worker years) and then dividing by the total labor hours for each HSL. The calculated incident rates are provided in Table 7.

Table 7: Incident Rate (per 200,000 hr)

Heat Stress Level	All	First Aid	Medical Treatment	Restricted Duty	Days Away From Work
Acute Injury					
0	26.9	17.4	6.9	1.2	1.4
1	41.6	34.5	4.1	0.8	2.2
2	61.1	49.4	7.3	1.1	3.3
3	49.9	41.2	6.1	0.5	2.2
>3	51.7	43.4	5.3	0.8	2.3
Heat-Related					
0	4.0	2.6	1.4	0.0	0.0
1	25.2	21.1	3.1	0.1	0.9
2	39.7	34.6	3.8	0.1	1.2
3	40.7	35.4	4.5	0.0	0.8
>3	77.1	67.7	7.4	0.1	2.0
All Incidents					
0	31.0	20.0	8.4	1.2	1.4
1	66.8	55.6	7.2	0.9	3.1
2	100.8	84.0	11.1	1.2	4.5
3	90.6	76.6	10.6	0.5	3.0
>3	128.8	111.0	12.7	0.9	4.2

An examination of the incident rates shows a large increase from HSL 0 to HSL 1 for both acute injuries and heat-related disorders and then again from HSL 1 to HSL 2 when all the incident severity classifications are considered together. This also holds true for the first aid severity classification. From HSL 2 to HSL 3 there is a drop in the average incident rate for all incidents. The incident rates for HSL 3 to HSL ≥ 3 then again increase for all incident types. No statistically significant pattern was evident for the restricted duty and days away from work severity classes given the limited number of incidents in these severity classifications.

With HSL 0 serving as the baseline, the rate ratios for each HSL by incident type and severity were calculated. Table 8 provides a summary of those rate ratios. As seen in the table, nearly all rate ratios for each incident type were found to be statistically significant and indicated an increased probability for injury at each HSL. The incident severity rate ratios for first aid were also found to be statistically significant indicating an increased probability of the need for first aid with each increase in the specific HSL. Beyond the first aid classification the incident severities by class were not found to be statistically significant due to the declining numbers and widening confidence intervals. The rate ratios for the three incident types (All Incidents, Heat-Related, and Acute Injury), and First Aid are displayed in Figures 1 through 4 along with their 95% CIs.

Table 8: Rate Ratios by Heat Stress Level (HSL) by Incident Type and by Incident Severity.

Type				Severity for All Incidents			
HSL	All Incidents	Heat-Related	Acute	First Aid	Medical Treatment	Restricted Duty	Days Away From Work
0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
1	2.2*	6.2*	1.5*	2.8*	0.9	0.8	2.1
2	3.3*	9.8*	2.3*	4.2*	1.3	1.0	3.2
3	2.9*	10.1	1.9*	3.8*	1.3	0.4	2.1
>3	4.2*	19.1*	1.9	5.5*	1.5	0.8	2.9

* Statistically significant differences for adjacent HSLs at alpha = 0.05

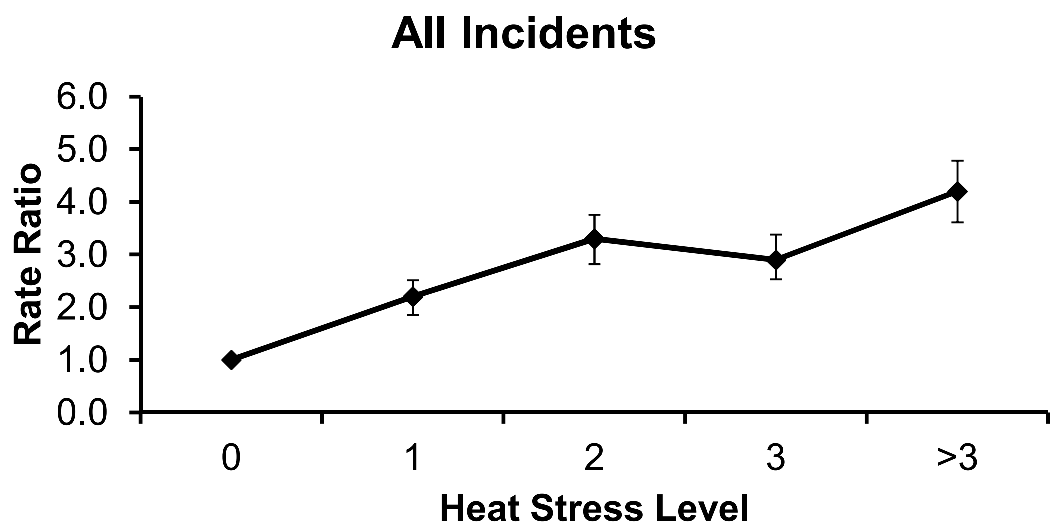

Figure 1: Rate Ratios for All Incidents by Heat Stress Level with 95% CI.

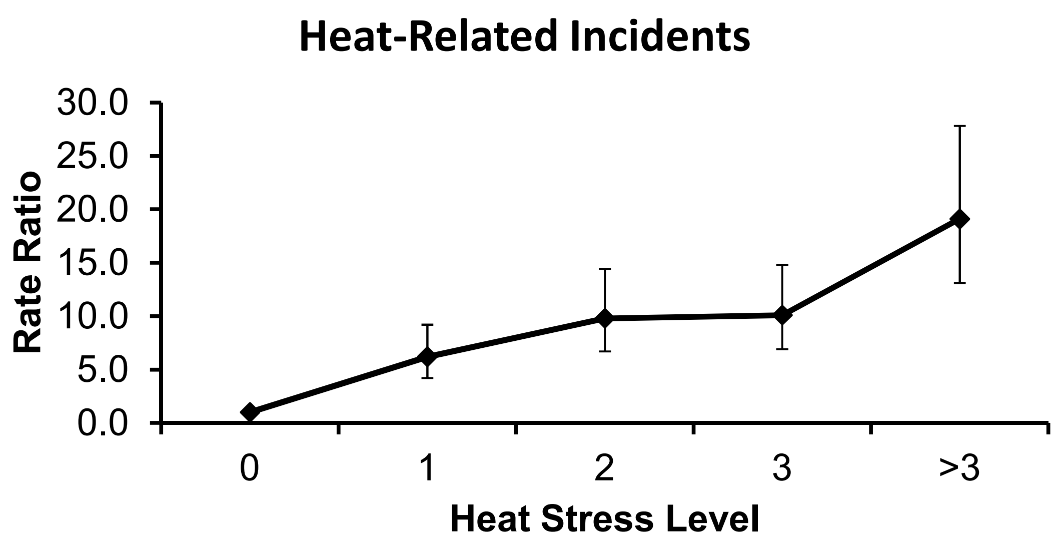

Figure 2: Rate Ratio for Heat-Related Incidents (Disorders) by Heat Stress Level with 95% CI.

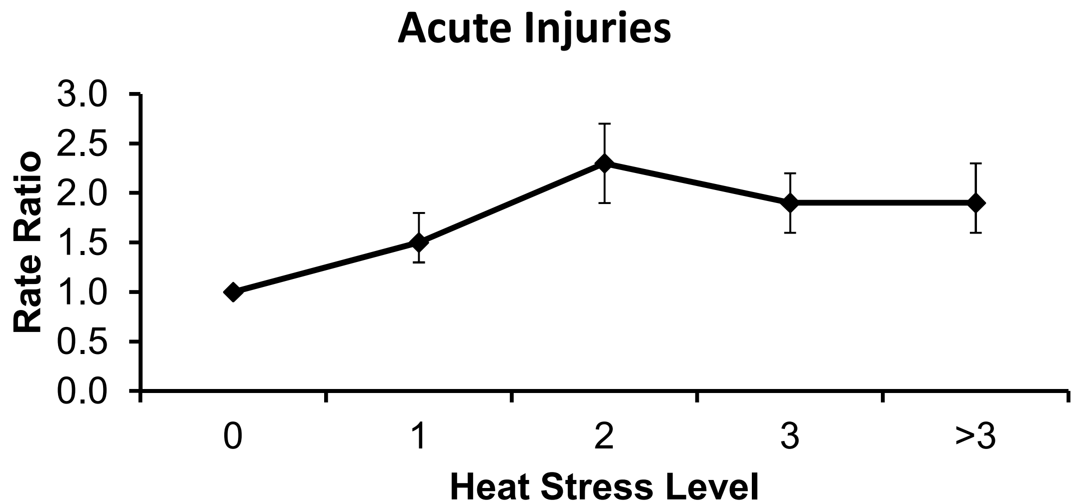

Figure 3: Rate Ratio for Acute Injuries by Heat Stress Level with 95% CI.

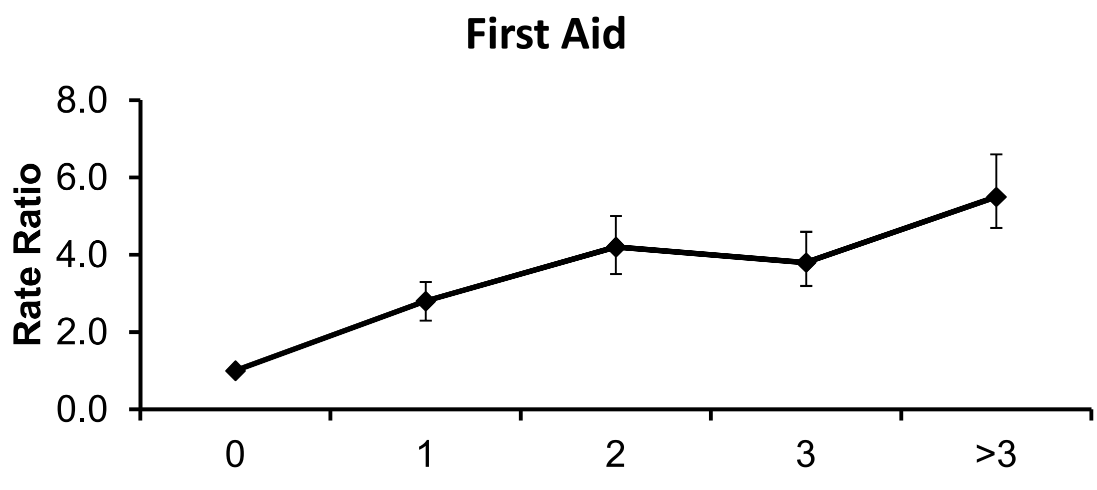

Figure 4: Rate Ratio for incidents requiring First Aid by Heat Stress Level with 95% CI.

Discussion and Conclusions

The objective of this study was to examine the relationship between thermal conditions and (1) heat-related disorders and (2) acute injury by taking a look at the prevalence of reported injuries during the Deepwater Horizon clean-up operations. What constituted a heat-related incident for this study was not necessarily a diagnosed heat-related disorder, but rather any record in the database that associated an incident, either through primary or secondary complaint or indicated by code, to heat. For an incident to be classified as an acute injury it had to be related to a specific event, specific moment or specific mishap and have an immediate effect on the individual exposed. An additional requirement was that it be loosely associated with individual actions or mishandlings. This excluded, for example, insect bites, chronic or systematic diseases and disorders, infections, parasitic diseases, and chemical exposures not specifically caused by mishandling by an individual. In all, the inclusion criteria for both incident types were somewhat broad.

The determination of labor-hours was based on the average number of workers assigned to the clean-up operations. The numbers of workers were provided directly from BP. Approximations began with an assumption of an average 6-day workweek at 12 hours per day from May through December 2010 and 10 hours per day from January through April. These hours were estimated by BP. Another approximation was an equal division of labor-hours between the two locations, which had somewhat different weather profiles. While an inflation in labor-hours could lower the incident rate, the estimation by BP was accepted for this study to be relatively accurate. The equal division of labor-hours could lead to a slightly increased incident rate in one ICP and a slightly decreased incident rate in the other ICP; however, given that the rate ratios were calculated from the sum of the hours and the sum of the number of injuries from both ICPs this estimation should have little effect on rate ratios.

With a review of incident rates and rate ratios for All Incidents, Heat-Related Disorders, Acute Injuries, and First Aid, it became evident that there was a substantial jump from the reference Heat Stress Level of 0 to HSL 1 and then again to HSL 2. The rate ratio for Heat-Related Disorders at HSL 1 was 6.2 (95% confidence interval: Lower Confidence Limit [LCL]=4.2, Upper Confidence Limit [UCL]=9.2). At HSL 2 the corresponding Rate Ratio was 9.8 (LCL=6.7, UCL=14.4). The WBGT trigger for the heat stress management program was about 30 °C-WBGT, which is the starting point for HSL 3. Therefore, the increased rate ratios at HSL 1 and 2 suggested a lower threshold for attending to heat stress related disorders, and this is supported by the observation that most of the cases below the threshold were First Aid. When the HSL was greater than 3, there was a jump in the rate ratio to 19. A similar observation on rate ratios and broad confidence intervals was reported by Bernard for aluminum smelters.[29]

The probability of sustaining an acute injury also increased at HSL 1 and 2 (RR=1.5, 95% CI=1.3 to 1.8 and RR=2.3, 95% CI=1.9 to 2.7, respectively). These results indicated that there was a significant increase in acute injury rates at thermal conditions above 24 ºC-WBGT and below 30 ºC-WBGT. The occupational exposure limit would be about 30 ºC-WBGT for light work demands, which coincides with the start of HSL 3. That is, prior to reaching the occupational exposure limit there were significant increases in the probability of sustaining an acute injury. With heat stress level 0 representing temperatures < 24 ºC-WBGT it included the range (17 to 23 ºC-WBGT) that Ramsey described as the minimum Unsafe Behavior Index for light, moderate, or heavy workloads.[10] Beyond that range (24ºC and 30ºC-WBGT) the thermal stress level enters the range where, according to Ramsey, unsafe behaviors begin to increase, while effective work practices have not yet been introduced.[10, 25]

As seen in Table 7, from HSL 2 to HSL 3 there is a drop in the incident rate for All Incidents. It also follows that the corresponding rate ratio in HSL 3 is lower than that of HSL 2 for All Incidents (Figure 1). This may be a result of the aggressive heat stress management program implemented by BP following the ACGIH® TLV® guidelines.

Beyond the very broad inclusion criteria, the major limitation of this study was the assessment of the actual heat stress. It was not possible to assign a level of heat stress based on WBGT that was adjusted for work demands and clothing requirements. A further weakness is that the incidents may be confounded by fatigue.

In conclusion, the working hypothesis for this study was that heat exposure would result in increases in heat-related disorders and in an increase in the incidences of acute injury. Given that overall incident rates of heat-related disorders and acute injuries were found to increase as thermal conditions increased, the null hypothesis was rejected. The incident rates in HSL 1 and HSL 2 for both heat-related disorders and acute injuries increased at thermal conditions generally considered to be below the occupational exposure limit of 30 ^{o}C-WBGT. This evidence suggested that the current OEL is not protective of acute injury and perhaps not sufficiently protective of heat-related disorders. Above 33 ^{o}C-WBGT, the risk for heat-related disorders increased substantially. Well above the OEL, individuals working at these temperatures during the clean-up were 19 times more likely to experience a heat-related incident.

REFERENCES

[1] National Weather Service Weather Forecast Office, The July 1936 Heat Wave, National Oceanic and Atmospheric Administration 2012. Available at: http://www.crh.noaa.gov/ilx/?n=july1936heat. Accessed May 5, 2012.

[2] Greenberg JH, Bromberg J, Reed CM, Gustafson TL, Beauchamp RA. The Epidemiology of Heat-Related Deaths, Texas – 1950, 1970-79, and 1980. American Journal of Public Health. 1983; 73:805-807.

[3] National Center for Health Statistics. *Mortality public use computer data tapes for years 1979-1991.* Hyattsville. MD: National Center for Health Statistics. 1994.

[4] Hanna EG, Kjellstrom T, Bennett C, Dear K. Climate Change and Rising Heat: Population Health Implications for Working People in Australia. Asia-Pacific Journal of Public Health. 2011;23(2 Suppl):14S-26S.

[5] Selkirk GA, McLellan TM. Physical Work Limits for Toronto Firefighters in Warm Environments. Journal of Occupational and Environmental Hygiene. 2004;1:199-212.

[6] BLS. Injuries, illnesses, and fatalities [online]. Washington DC: Bureau of Labor Statistics; 2012. Available at: http://www.bls.gov/iif/. Accessed January 9, 2012.

[7] Centers for Disease Control and Prevention. (2008). MMWR Weekly: Heat-Related Deaths Among Crop Workers – United States, 1992-2006. Available at:http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5724a1.htm. Accessed June 23, 2012.

[8] Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses. Journal of Athletic Training. 2002;37(3):329-343.

[9] OSHA Heat Stress Fact Sheet: Protecting Workers from the Effects of Heat. (2011). Available at: http://www.osha.gov/OshDoc/data_Hurricane_Facts/heat_stress.pdf. Accessed May 16, 2012.

[10] Ramsey JD, Burford CL, Beshir MY, and Jensen RC. Effects of Workplace Thermal Conditions On Safe Work Behavior. *Journal of Safety Research*. 1983;14:105-114.

[11] King BS, Gibbins JD. Health Hazard Evaluation of Deepwater Horizon Response Workers. National Institute for Occupational Safety and Health. Available at: http://www.cdc.gov/niosh/hhe/.

[12] Ramsey JD. Task performance in heat: a review. Ergonomics. 1995;38:154-165.

[13] Hancock PA, Vasmatzidis I. Effects of heat stress on cognitive performance: The current state of knowledge. International Journal of Hyperthermia, 2003;19:355–372.

[14] Hancock PA, Vasmatzidis I. Human occupational and performance limits under stress: the thermal environment as a prototypical example. Ergonomics. 1998; 41:1169-1191.

[15] Centers for Disease Control and Prevention. Working in Hot Environments. DHHS (NIOSH) Publication Number 86-112. 1986. Available at: http://www.cdc.gov/niosh/docs/86-112/.

[16] Epstein Y, Keren G, Moisseiev J, Gasko O, Yachin S. Psychomotor deterioration during exposure to heat. Aviation, Space, and Environmental Medicine 1980;51:607-610.

[17] Chen ML, Chen CJ, Yeh WY, Huang JW, Mao IF. Heat Stress Evaluation and Worker Fatigue in a Steel Plant. AIHA Journal. 2003;64:352-359.

[18] Grandjean AC, Grandjean NR. Dehydration and Cognitive Performance. Journal of the American College of Nutrition. 2007;26:549S-554S.

[19] Parsons K. Human Thermal Environment. The Effects of Hot, Moderate and Cold Temperatures on Human Health, Comfort and Performance. 2nd ed. New York, NY: CRC Press; 2003.

[20] Froom P, Caine Y, Shochat I, Ribak J. Heat Stress and Helicopter Pilot Errors. Journal of Occupational Medicine. 1993;35:720-724.

[21] Jackson LL, Rosenberg HR. Preventing Heat-Related Illness Among Agricultural Workers. Journal of Agromedicine, 2010;15: 200-215.

[22] Sharp RL. Role of Sodium in Fluid Homeostasis with Exercise. Journal of the American College of Nutrition. 2006; 25: 231S-239S.

[23] Gopinathan PM, Pichan G, Sharma VM: Role of dehydration in heat stress-induced variations in mental performance. Arch Environ Health. 1988;43:15-17.

[24] Beshir MY, Ramsey JD, Burford CL. Threshold values for the Botsball: A field study of occupational heat. Ergonomics. 1982;25:247-254.

[25] ACGIH. Threshold Limit Values for Chemical Substances and Physical Agents & Biological Exposure Indices. American Conference of Governmental Industrial Hygienists, Cincinnati, OH. 2012.

[26] Weather Source, LLC. Available at: http:weathersource.com.

[27] Bernard TE. (2012, June 26). Personal Communication.

[28] Bernard TE, Pourmoghani M. Prediction of Workplace Wet Bulb Globe Temperature. Applied Occupational and Environmental Hygiene. 1999;14:126-134.

[29] Beranrd TE. Chapter 28: Occupational Heat Stress, in Bhattacharya A, McGlothlin JD, eds. Occupational Ergonomics: Theory and Applications. 2nd ed. Boca Raton, FL: CRC Press; 2012.