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SHORT REPORT

Influence of age, geographical region, and work unit on heat strain symptoms: a cross-sectional survey of electrical utility workers

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ABSTRACT

This study assessed self-reported heat strain symptoms in workers of a state wide electrical utility distributor to determine risk differences between age groups, geographical work regions and work units. Out of a total 3,250 workers, 918 (~28%) outdoor staff completed an online survey, which assessed the frequency of self-reported heat strain symptoms in the work and post-work settings, factors contributing to symptoms and symptom management. Heat strain symptoms were grouped into chronic low-grade cases and isolated high-grade cases based on the severity and frequency of symptoms. The risk (likelihood) of an employee being classified as either a chronic low-grade or isolated high-grade case was calculated and compared to the mean risk of all categories to determine risk difference, expressed as −1.00 to 1.00. For chronic low-grade cases, the 41–50 years age group had significantly increased risk (+0.08, $p < 0.05$) while the over 60 years age group had significantly decreased risk (-0.14, $p < 0.05$). Two of the three regions ($p < 0.01$) and three of the nine work units also demonstrated risk differences ($p < 0.01$) for chronic low-grade cases. Work units were the sole grouping to demonstrate risk difference for isolated high-risk cases. Work units with greater exposure to heat and higher requirement for protective clothing, such as Underground (+0.19, $p < 0.05$), Overhead – Predominantly Live Line (+0.18, $p < 0.01$), and Overhead – Distribution and Transmission (+0.11, $p < 0.05$) were at greater risk of reporting heat stress symptoms. This study demonstrates that the pattern of self-reported chronic low-grade heat strain cases differs to isolated high-grade cases within the electrical utility industry. Age, geographical location, and work unit independently alter the risk of chronic low-grade heat strain, while the risk of isolated high-grade heat strain was only related to work unit. These outcomes support implementation of a flexible and targeted approach to heat stress management in large and diverse organizations in which employees are routinely exposed to heat.

KEYWORDS
Environmental risk factors; self-reported symptoms; work units

Introduction

Australian outdoor workers can experience harsh climatic conditions across all the continent's climatic zones (Jay and Brotherhood 2016). This is particularly evident during the summer months with the prevention of heat-related occupational injuries becoming a significant focus area of organizational Health, Safety and Environment (HSE) teams (Xiang et al. 2015). While climatic exposure is generally implicated in occupational heat-related illness and injuries, a host of factors may contribute, including occupational task demands, the wearing of personal protective equipment (PPE), and personal factors (Oppermann et al. 2018).

Through generation and distribution of power to customers, the electrical utility industry combines the aforementioned elements through routine exposure of workers to high ambient temperatures and humidity. The net heat load of these workers is also influenced by radiant heat sources and the requirement to wear PPE. Increased metabolic demands of time-sensitive workloads during power restorations and emergency responses further exacerbate the risk of heat impacting worker health.

Despite the size of the industry globally, relatively little research has been published regarding the impact of heat on electrical utility workers. To date, research

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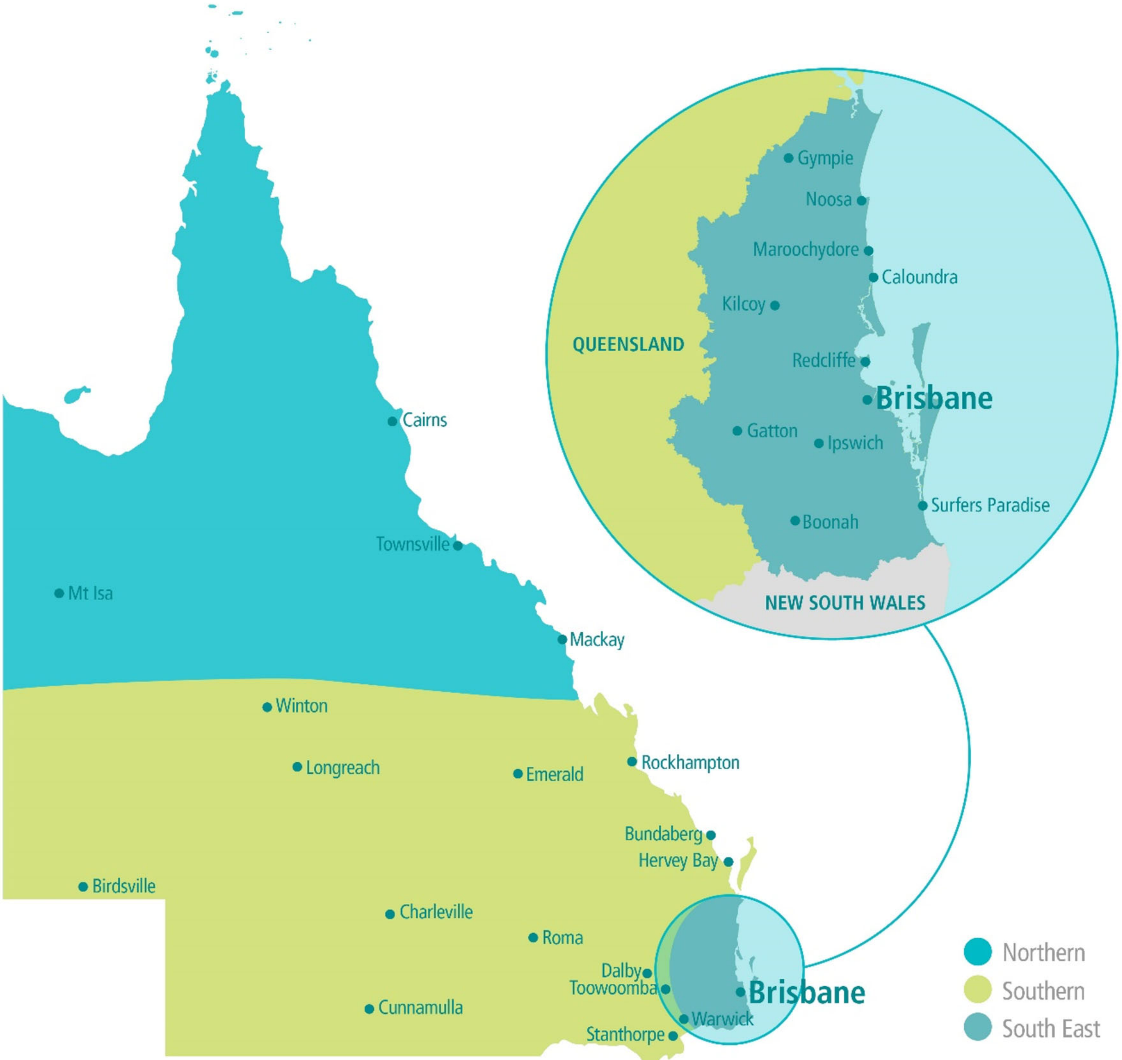

Figure 1. The delineation of the three geographical regions (Northern, Southern, and South East) across the state of Queensland.

has focused on physiological responses, including core body temperatures reported from Australian (n = 20) (Brearley et al. 2015) and North American (n = 32) (Meade et al. 2015) workers. Notwithstanding the modest sample, that >50% of the monitored workers attained core temperatures exceeding the threshold limit of 38.0 °C (ISO9886; WHO) suggests heat stress is an issue within the electrical utility industry. While spot core temperature measurements during a work shift provide some insight into the risk of heat-related illness, continuous monitoring is necessary as thermal strain may be cumulative across consecutive work shifts (Meade et al. 2017). Furthermore, the response to working in the heat across an entire season, as occurs in the context of field settings, may vary considerably to what is observed during a given work shift. Typically, electrical utility workers are not physiologically monitored in the field. Under standard conditions, workers monitor themselves and their colleagues based upon subjective signs and symptoms (Oppermann et al. 2018). Despite this widespread approach, the prevalence of self-reported heat stress symptoms in electrical utility workers remains largely unreported, thereby preventing analysis of potential contributors to heat stress, including workers age (Larose et al. 2013), their work region (Brearley et al. 2016), and/or their work unit. Hence, the purpose of this study was to assess the self-reported frequency of heat strain symptoms in Australian electrical utility workers to determine if risk was associated with age group, geographical work region, and/or work unit.

Methods

Study population

The study population (N = 3,250) was a sample of convenience, comprising of field-based employees in an Australian, state government-owned, electricity

Table 1. Mean historical storm season environmental conditions.

Environmental Variable	South East Region	Southern Region	Northern Region
Maximum Temperature (°C)	27.9	31.0	31.8
Minimum Temperature (°C)	18.3	18.8	21.6
Days $>$ 30°C (%)	21.5	58.2	67.9
3pm Relative Humidity (%)	57.4	39.4	53.1
3pm Wet Bulb Temperature (°C)	20.6	20.3	22.7

distributor. The organization was Australia's largest energy distributor and services the entire state of Queensland (Figure 1), an area covering approximately 715,000 square miles (18,50,000 km^2). Field-based workers are responsible for designing, planning, installing, and maintaining the overhead and underground electricity network across the state of Queensland.

Survey and timing

The cross-sectional questionnaire incorporated elements from previous heat stress surveys (Hunt 2011; Carter et al. 2020) and was hosted by SurveyMonkey (San Mateo, CA, USA)—copies of the complete survey are available from the lead author upon request. Potential respondents to this survey were advised of its availability via a range of organizational communication channels (e.g., email with embedded link, work group meetings, private Facebook account only accessible by staff, internal intranet news service, SMS to work mobile). The questionnaire assessed heat exposure in the work environment, negative impacts, and symptoms of heat exposure during the October to April period of 2018–2019, otherwise known as the "Storm Season" within the Australian electrical utility industry. This period crosses the summer months and results in higher workload due to storm damage, related network emergency repairs, and service restoration to the community. Mean historical storm season environmental conditions can be seen in Table 1. This study had ethics approval (institutional ethics approval number ECN-19-036), with electronic informed consent provided by participants prior to survey commencement. The questionnaire was made available online in May 2019 for a period of approximately four weeks. As part of standard workplace training, workers undergo heat stress education that includes recognition of signs and symptoms of heat strain. As such, this cohort of workers were familiar with the terminology used in the survey.

While the term "field based workers" is used to describe workers that are responsible for designing, planning, installing, and maintaining the overhead and underground electricity network, different work units with differing roles exist under the broad classification of field workers. Respondents represented members of all nine organizational functional work units: (i) Underground (distribution and transmission); (ii) Overhead (distribution and transmission); (iii) Overhead (predominantly live line); (iv) Substations; (v) Test and Secondary Systems; (vi) Customer Service; (vii) Remote and Embedded Generation; (viii) Support Teams (e.g., design and engineering); and (ix) Multifunctional Crew. Further, and as per the organizational structure, workers were divided into three geographical regions: Northern, Southern, and South East (Queensland) (Figure 1).

Outside of large-scale emergencies such as natural disasters, workers generally only operate within their geographical region. As such workers will generally only be exposed to the climatic conditions within the geographical region they are located. Worker age, and years worked in each respective region, can be seen in Tables 2 and 3, respectively. Out of those workers, 99.5% were full-time, working a minimum of 72 hr across a 9-day fortnight. As an example, a worker could work 5 days in the first week of a given fortnight and 4 days in the second week, resulting in 9 days of work being completed over a 14 day timeframe. While a worker completes a minimum of 72 hours across those 9 days, emergency restoration work could result in additional hours being completed as overtime.

Statistical analysis

Data analysis was performed using SPSS (V25) (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Armonk, NY). For the purpose of analysis, heat strain symptoms from the survey data (Table 4) were grouped to form two case definitions of heat illness (i.e., heat exhaustion and heat stroke). This is in line with previously published research (Carter et al. 2020). A chronic low-grade case was defined as workers reporting daily or weekly frequency of any of the following symptoms: rash, muscle cramps, headache, nausea, dizziness, fatigue, and irritability. An isolated high-grade case was defined by any report of vomiting, fainting, irrational behavior, low coordination, confusion, loss of consciousness, or convulsions during the study period.

Binary variables (0, 1) were computed to identify cases of: (i) chronic low-grade and (ii) isolated high-grade for use as response variables in regression models. The SPSS GENLIN procedure was used to fit binary logistic models for these regression analyses. The binomial probability distribution was assumed for the response variables. The logistic function was used as the link function between the response and predicator variables. Model results were back-transformed from the logistic scale to the probability (or proportion) scale for reporting.

Risk was estimated as the frequency of the target category (e.g., frequency of chronic heat stress) as a proportion of the frequency of all categories (e.g., frequency of chronic heat stress + frequency of not chronic heat stress), i.e., risk estimate = frequency of target category/frequency of all categories.

In order to avoid a multiplicity of comparisons between pairs in large sets of categories, the risk experienced by each category was compared to the mean risk for all categories (e.g., risk for workers in the substations work unit–mean risk for workers in all work units). This is presented as estimated risk differences in the results. A negative risk difference indicates that the category (e.g., substations work unit) has a lower risk than the mean risk for all work units combined. A positive risk difference indicates the opposite, that is that the category (e.g., substations work unit) has a higher risk than the mean risk for all work units combined. Statistical significance was set at $p < 0.05$, and the Bonferroni method was used to adjust for multiple comparisons.

Table 2. Number and percentage of workers (N = 918) in each age group across the study cohort.

Age group	n (%)
<21	5 (0.5)
21–30	112 (12.2)
31–40	293 (31.9)
41–50	272 (29.6)
51–60	178 (19.4)
>60	58 (6.3)

Table 3. Years worked in the geographical region that the worker (N = 918) was based in at the time of the survey.

Years	n (%)
<1	16 (1.7)
1–5	77 (8.4)
6–10	159 (17.3)
>10	666 (72.6)

Results

A total of 918 employees completed the survey, representing a participation rate of ∼28%. Of these, ∼95% were male, ∼4% were female, and ∼1% did not disclose gender.

Heat strain symptoms

Chronic low-grade cases

Risk. Table 5 summarizes the risk of an employee being classified as a chronic low-grade case based on age group, work region, and work unit. The risk of being classified as a chronic low-grade case ranged from 36–58% across age groups, from 44–60% across work regions, and from 18–71% across work units.

Risk difference. Table 6 reports the estimated differences in risk of chronic low-grade cases between age groups, work regions, and work units. Two of the five age groups had risk differences that differed significantly from the mean risk for all age groups combined. The 41–50 year old age group was at significantly increased risk (+0.08, $p < 0.05$) and the over 60 years age group was at significantly less risk (-0.14, $p < 0.05$). The Southern region was at significantly less risk (-0.08, $p < 0.01$) while the South East region was at significantly increased risk (+0.07, $p < 0.01$).

Three of the nine work units had risk differences that differed significantly from the mean risk for all work units

Table 4. Frequency of heat stress symptoms prior to grouping and analysis. Raw data displayed is the number of workers (N = 918) experiencing a given symptom. The percentage of the sample experiencing the symptom is shown in brackets.

Symptoms	Never	Rarely	Monthly	Weekly	Daily
Red rash on skin	410 (44.7)	248 (27.0)	96 (10.5)	108 (11.7)	56 (6.1)
Muscle cramp	324 (35.3)	293 (31.9)	134 (14.6)	129 (14.1)	38 (4.1)
Headache	185 (20.2)	296 (32.2)	187 (20.4)	214 (23.3)	36 (3.9)
Nausea	536 (58.4)	273 (29.7)	71 (7.7)	32 (3.5)	6 (0.7)
Dizziness	542 (59.0)	271 (29.5)	62 (6.7)	37 (4.0)	6 (0.7)
Vomiting	828 (90.2)	80 (8.7)	6 (0.7)	1 (0.1)	3 (0.3)
Fainting	861 (93.8)	50 (5.5)	3 (0.3)	3 (0.3)	1 (0.1)
Fatigue	116 (12.7)	296 (32.2)	173 (18.9)	239 (26.0)	94 (10.2)
Irritability	258 (28.1)	257 (28.0)	152 (16.6)	172 (18.7)	79 (8.6)
Confusion	624 (68.0)	212 (23.1)	37 (4.0)	30 (3.3)	15 (1.6)
Irrational behavior	612 (66.7)	211 (23.0)	46 (5.0)	34 (3.7)	15 (1.6)
Low coordination	604 (65.8)	235 (25.6)	48 (5.2)	21 (2.3)	10 (1.1)
Loss of consciousness	898 (97.8)	16 (1.7)	0 (0.0)	3 (0.3)	1 (0.1)
Convulsions/seizures	909 (99.0)	8 (0.9)	0 (0.0)	1 (0.1)	0 (0.0)

Table 5. Risk of an employee being classified as a chronic low-grade or isolated high-grade case based on age group, work region, and work unit.

		Chronic low-grade cases			Isolated high-grade cases		
Predictor	Categories	Risk	SE	95% CI	Risk	SE	95% CI
Age Group	Up to 30	0.56	0.05	0.47–0.65	0.44	0.05	0.36–0.54
	31–40	0.55	0.03	0.49–0.60	0.43	0.03	0.37–0.49
	41–50	0.58	0.03	0.52–0.64	0.53	0.03	0.47–0.59
	51–60	0.45	0.04	0.38–0.52	0.49	0.04	0.42–0.56
	Over 60	0.36	0.06	0.25–0.49	0.45	0.07	0.33–0.58
Work Region	Northern	0.53	0.03	0.47–0.58	0.50	0.03	0.44–0.55
	Southern	0.44	0.03	0.39–0.50	0.42	0.03	0.36–0.48
	South East	0.60	0.03	0.55–0.65	0.50	0.03	0.45–0.56
Work Unit	Underground	0.70	0.06	0.58–0.80	0.63	0.06	0.51–0.73
	Overhead (D&T)	0.56	0.03	0.50–0.61	0.54	0.03	0.48–0.60
	Overhead (LL)	0.71	0.04	0.63–0.78	0.61	0.04	0.53–0.69
	Substations	0.45	0.06	0.34–0.56	0.43	0.06	0.32–0.54
	Test and Secondary Systems	0.48	0.06	0.37–0.61	0.38	0.06	0.27–0.50
	Customer Service	0.64	0.05	0.54–0.74	0.50	0.05	0.40–0.60
	Remote and Embedded Generation	0.40	0.11	0.21–0.62	0.25	0.10	0.11–0.48
	Support Teams	0.18	0.04	0.12–0.26	0.19	0.04	0.13–0.27
	Multifunctional Crew	0.48	0.06	0.37–0.61	0.45	0.06	0.34–0.57

Table 6. The estimated differences in risk of chronic low-grade or isolated high-grade case between age groups, work regions, and work units.

		Chronic low-grade cases				Isolated high-grade cases			
Predictor	Categories	Risk	SE	95% CI	P	Risk	SE	95% CI	P
Age Group	Up to 30	0.06	0.04	−0.03–0.16	0.58	−0.02	0.04	−0.12–0.07	1.00
	31–40	0.05	0.03	−0.02–0.11	0.62	−0.04	0.03	−0.11–0.03	0.95
	41–50	0.08	0.03	0.01–0.15	0.04*	0.06	0.03	−0.01–0.13	0.18
	51–60	−0.05	0.03	−0.13–0.03	0.70	0.02	0.03	−0.06–0.10	1.00
	Over 60	−0.14	0.05	−0.26–0.00	0.04*	−0.02	0.05	−0.15–0.11	1.00
Work Region	Northern	0.00	0.02	−0.06–0.07	1.00	0.02	0.02	−0.04–0.09	1.00
	Southern	−0.08	0.02	−0.15–0.01	0.00*	−0.05	0.02	−0.12–0.01	0.08
	South East	0.07	0.02	0.01–0.14	0.00*	0.03	0.02	−0.03–0.09	0.55
Work Unit	Underground	0.19	0.05	0.07–0.30	0.00*	0.19	0.06	0.06–0.31	0.01*
	Overhead (D&T)	0.05	0.03	−0.02–0.12	1.00	0.11	0.03	0.03–0.18	0.02*
	Overhead (LL)	0.20	0.04	0.11–0.29	0.00*	0.18	0.04	0.08–0.27	0.00*
	Substations	−0.06	0.05	−0.17–0.60	1.00	−0.01	0.05	−0.12–0.11	1.00
	Test and Secondary Systems	−0.03	0.06	−0.15–0.10	1.00	−0.06	0.06	−0.18–0.07	1.00
	Customer Service	0.13	0.05	0.02–0.24	0.06	0.07	0.05	−0.04–0.18	1.00
	Remote and Embedded Generation	−0.11	0.10	−0.30–0.11	1.00	−0.18	0.09	−0.33–0.05	0.26
	Support Teams	−0.33	0.04	−0.40–0.24	0.00*	−0.24	0.04	−0.32–0.15	0.00*
	Multifunctional Crew	−0.03	0.06	−0.15–0.10	1.00	0.02	0.06	−0.10–0.15	1.00

*Significantly different from the mean risk of all categories for the predictor variable ($P<.05$).

combined. Underground (+0.19, $p < 0 .01$) and Overhead (predominantly live line) (+0.20, $p < 0.01$) were at significantly increased risk, while support teams were at significantly less risk (-0.33, $p < 0.01$).

Isolated high-grade cases

Risk. Table 5 outlines the risk of an employee being classified as an isolated high-grade case based on age group, work region, and work unit. The risk of being classified as an isolated high-grade case ranged from 43–53% across age groups, from 42–50% across work regions, and from 19–63% across work units.

Risk difference. Table 6 reports the estimated differences in risk of isolated high-grade cases between age groups, work regions, and work units. None of the five age groups had risk differences that varied significantly from the mean risk for all age groups combined. While the three regions did not demonstrate risk differences that differed significantly from mean risk for all age regions combined, there was a trend toward Southern having a lower risk (-0.05, $p = 0.08$). Four of the nine work units had significant risk differences. Underground (+0.19, $p < 0.05$), Overhead (distribution and transmission) (+0.11, $p < 0.05$), and Overhead (predominantly live line) (+0.18, $p < 0.01$) were at significantly increased risk, while support teams were at significantly less risk (-0.24, $p < 0.01$).

Discussion

It is well documented that numerous task-specific factors, such as exposure to solar radiation, uniforms, PPE, metabolic demands of the job, radiant heat sources, and capacity to self-pace influence the thermal load that a worker is exposed to (Hodder and Parsons 2007; Jay and Brotherhood 2016; Miller et al. 2011; Yang and Chan 2017). In the present study, the observed risk differences between work units were largely expected from a thermal physiological perspective. Roles that had greater exposure to environmental heat, radiant heat sources, required more extensive PPE, experienced less air flow, and/or had a higher metabolic requirement, such as Underground (Distribution and Transmission) and Overhead (predominantly live line), were associated with higher risks of both chronic low-grade cases and isolated high-grade cases (Tables 5 and 6). As such, electrical utility workers cannot be grouped as a single unit and these risk differences between working groups should be considered when implementing risk mitigation strategies. As an example, some of the exposure to heat could be reduced in higher risk groups, such as overhead live line workers, by scheduling more of the planned maintenance works to be conducted in the cooler months of the year.

The present data was collected in a large cohort that covered the entire state of Queensland, Australia, an area of approximately 715,000 square miles (18,50,000 km^2). Thus, it represented a unique opportunity to examine the impact of regional climatic variations. The Northern region not being at increased risk may appear aberrant since the Northern region is classified as a tropical climate zone vs. Southern (mostly arid/semi-arid) and South East (Subtropical) regions. However, employees in the Northern region are exposed to hot and humid conditions year round, which may be protective as they are likely chronically heat acclimatized (Brearley et al. 2015; Brearley et al. 2016). Due to less heat exposure during the winter months workers in the South East may not be as well adapted for heat and humidity, particularly early in the summer season (Lui et al. 2014). Likewise, the Southern region being predominantly arid or semi-arid typically experiences significantly less humidity and much drier heat during summer. It is well established that evaporative heat loss is more efficient and thermoregulatory strain is lower in hot dry conditions *vs.* hot humid conditions (Maughan et al. 2012; Mekjavic et al. 2017; Moyen et al. 2014), that likely explains the lower risk in the Southern Region workforce.

Age-associated declines in the physiological response to heat have been reported as early as age 40 years (Larose et al. 2013) and become more pronounced by age 60 years, making over 60s a vulnerable cohort (Balmain et al. 2018). In this study the over 60s age group were the only group to have a risk of chronic low-grade cases that was significantly lower than the risk for all age groups combined (Table 6), possibly due to a progressive transition into less physically demanding roles (e.g., supervisory). Only the 41–50 year age group was at significantly greater risk of chronic low-grade cases (Table 6). This is attributed to this age group still potentially performing a significant amount of metabolically demanding physical work, which is exacerbated by this age bracket being associated with a declining capacity to dissipate heat when compared to younger workers (Larose et al. 2013).

A key observation was the high number of workers within the study sample that experienced chronic low-grade symptoms or isolated high-grade symptoms (Table 5). In contrast, across the field workforce of more than 3,250 employees, only 22 heat-related incident notifications were reported; of these, only one required hospitalization. The apparent disconnect between incident notifications and chronic low-grade symptoms is potentially attributed to under-reporting. It is possible that workers don't consider their low-grade symptoms worthy of reporting, but simply a by-product of working in the heat and something that is normalized and "self-managed" (Oppermann et al. 2018). Likewise, at times many such symptoms arise in the post-exposure period and are dealt with in the home environment. Previously, it has been suggested that there can be a latency period between exposure and symptom onset for many heat-related symptoms such as headache, irritability, and nausea. This late onset symptom cluster has been termed a "heat hangover" (Brearley 2016).

It is highly unlikely that cases of severe heat exhaustion or heat stroke would go unreported, as such cases would require medical intervention and would automatically generate an incident notification. Knowledge gained from experience working in the heat may allow a worker to be highly attuned to afferent thermoregulatory feedback. Consequently, experienced workers may be able to make behavioral adjustments that allow them to operate very close to severe heat illness (Schlader et al. 2011). Thus, a worker may occasionally experience severe symptoms without experiencing an explicit medical event that automatically generates an incident notification.

Inherent limitations should be considered when interpreting the results of this study. Participation was voluntary and as such a response bias may exist in the form of an over representation of symptomatic workers. Furthermore, the study was conducted across a single state within Australia and the results will not necessarily extend to workers in other climatic regions. Finally, the research was cross sectional in nature and required employees to recall their experiences of heat stress symptoms.

Conclusion

This paper is the first large-scale paper reporting on heat strain symptoms in Australian electrical utility workers. It presents evidence, within the context of the environmental setting, showing that workers will report a high frequency of heat strain symptoms when working across the hottest months of the year. Despite this, a very low frequency of heat-related medical events were noted during the same time period. It is possible that unmonitored workers, experienced in working in the heat, can use their symptoms as feedback and make behavioral adjustments that protect them from experiencing more serious heat illness.

From an OHSE perspective, heat risk is often managed within organizations in a "one size fits all" type manner. Furthermore, climatic factors are often given excessive weighting in risk mitigation. In the current study risk varied significantly based on age, region, and work unit, with most of that variation having sound underlying physiological explanation. The large risk differences observed across this occupational cohort highlights the need for a flexible and targeted approach to heat stress management in large and diverse organizations.

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Conflicts of interest

The lead author is an employee of Energy Queensland. The second author is a consultant of Energy Queensland.

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References

Balmain BN, Sabapathy S, Louis M, Morris NR. 2018. Aging and thermoregulatory control: the clinical implications of exercising under heat stress in older individuals. BioMed Res Int. 2018:830615. doi:10.1155/2018/8306154

Brearley M, Harrington P, Lee D, Taylor R. 2015. Working in hot conditions: a study of electrical utility workers in the Northern Territory of Australia. J Occup Environ Hyg. 12(3):156–162. doi:10.1080/15459624.2014.957831

Brearley M. 2016. Preliminary evidence of a heat hangover, a new heat illness classification for occupational settings? In Proceedings of Science of Sport, Exercise and Physical Activity in the Tropics, Townsville, Queensland.

Brearley MB, Norton I, Rush D, Hutton M, Smith S, Ward L, Fuentes H. 2016. Influence of chronic heat acclimatization on occupational thermal strain in tropical field conditions. J Occup Environ Med. 58(12):1250–1256. doi:10.1097/JOM.0000000000000902

Carter S, Oppermann E, Field E, Brearley M. 2020. The impact of perceived heat stress symptoms on work related tasks and social factors: a cross-sectional survey of Australia's monsoonal north. Appl Ergo. 82:102918. doi:10.1016/j.apergo.2019.102918

Hodder SG, Parsons K. 2007. The effects of solar radiation on thermal comfort. Int J Biometeorol. 51(3):233–250. doi:10.1007/s00484-006-0050-y

Hunt A. 2011. Heat strain. hydration status, and symptoms of heat illness in surface mine workers [PhD thesis]. Brisbane, QLD: Queensland University of Technology.

Jay O, Brotherhood JR. 2016. Occupational heat stress in Australian workplaces. Temperature (Austin). 3(3):394–411. doi:10.1080/23328940.2016.1216256

Larose J, Boulay P, Sigal RJ, Wright HE, Kenny GP. 2013. Age-related decrements in heat dissipation during physical activity occur as early as the age of 40. PLoS One. 8(12):e83148. doi:10.1371/journal.pone.0083148

Lui B, Cuddy JS, Hailes WS, Ruby BC. 2014. Seasonal heat acclimatization in wildland firefighters. J Therm Biol. 45:134–140. doi:10.1016/j.jtherbio.2014.08.009

Maughan RJ, Otani H, Watson P. 2012. Influence of relative humidity on prolonged exercise capacity in a warm environment. Eur J Appl Physiol. 112(6):2313–2321. doi:10.1007/s00421-011-2206-7

Meade R, D'Souza A, Krishen L, Kenny G. 2017. The physiological strain incurred during electrical utilities work over consecutive work shifts in hot environments: a case report. J Occup Environ Hyg. 14(12):986–994. doi:10.1080/15459624.2017.1365151

Meade R, Lauzon M, Poirier M, Flouris A, Kenny G. 2015. An evaluation of the physiological strain experienced by electrical utility workers in North America. J Occup Environ Hyg. 12(10):708–720. doi:10.1080/15459624.2015.1043054

Mekjavic IB, Ciuha U, Gronkvist M, Eiken O. 2017. The effect of low ambient relative humidity on physical performance and perceptual responses during load carriage. Front Physiol. 8:451. doi:10.3389/fphys.2017.00451

Miller V, Bates G, Schneider J, Thomsen J. 2011. Self-pacing as a protective mechanism against the effects of heat stress. Ann Occup Hyg. 55(5):548–555. doi:10.1093/annhyg/mer012

Moyen N, Ellis C, Ciccone A, Thurston T, Cochrane K, Brown E, Coburn JW, Judelson DA. 2014. Increasing relative humidity impacts low-intensity exercise in the heat. Aviat Space Environ Med. 85(2):112–119. doi:10.3357/asem.3787.2014

Oppermann E, Strengers Y, Maller C, Rickards L, Brearley M. 2018. Beyond threshold approaches to extreme heat: repositioning adaptation as everyday practice. Wea. Climate Soc. 10(4):885–898. doi:10.1175/WCAS-D-17-0084.1

Schlader ZJ, Simmons SE, Stannard SR, Mündel T. 2011. The independent roles of temperature and thermal perception in the control of human thermoregulatory behavior. Physiol Behav. 103(2):217–224. doi:10.1016/j.physbeh.2011.02.002

Xiang J, Hansen A, Pisaniello D, Bi P. 2015. Perceptions of workplace heat exposure and controls among occupational hygienists and relevant specialists in Australia. PLOS One. 10(8):e0135040. doi:10.1371/journal.pone.0135040

Yang Y, Chan AP. 2017. Role of work uniform in alleviating perceptual strain among construction workers. Ind Health. 55(1):76–86. doi:10.2486/indhealth.2016-0023