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Drivers of self-reported heat stress in the Australian labour force

Kerstin K. Zander[a,*], Simon A. Moss[b], Stephen T. Garnett[c]

[a] Northern Institute, Charles Darwin University, Darwin, Northern Territory, Australia
[b] School of Psychological and Clinical Sciences, Charles Darwin University, Darwin, Northern Territory, Australia
[c] Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, Northern Territory, Australia

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ABSTRACT

Heat stress causes reductions in well-being and health. As average annual temperatures increase, heat stress is expected to affect more people. While most research on heat stress has explored how exposure to heat affects functioning of the human organism, stress from heat can be manifest long before clinical symptoms are evident, with profound effects on behavior. Here we add to the little research conducted on these subclinical effects of environmental heat using results from an Australian-wide cross-sectional study of nearly 2000 respondents on their self-reported level of heat stress. Slightly less than half (47%) of the respondents perceived themselves as at least sometimes, often or very often stressed by heat during the previous 12 months. Health status and smoking behavior had the expected impact on self-reported perceived heat stress. There were also regional differences with people living in South Australia, Victoria and New South Wales most likely to have reported to have felt heat stressed. People generally worried about climate change, who had been influenced by recent heat waves and who thought there was a relationship between climate change and health were also more likely to have been heat stressed. Surprisingly average maximum temperatures did not significantly explain heat stress but stress was greater among people who perceived the day of the survey as hotter than usual. Currently heat stress indices are largely based on monitoring the environment and physical limitations to people coping with heat. Our results suggest that psychological perceptions of heat need to be considered when predicting how people will be affected by heat under climate change and when developing heat relief and climate change adaptation plans, at work, at home or in public spaces. We further conclude that the perception of temperature and heat stress complements measures that assess heat exposure and heat strain.

1. Introduction

Globally, February 2016 was the hottest month, seasonally adjusted, since records began in 1880 (NOAA, 2016). Before that 2014 and also 2015 had the highest globally-averaged temperatures (NASA, 2016). Besides higher average temperatures, more frequent and longer lasting heat waves are predicted for the coming decades (Meehl and Tebaldi, 2004; Perkins et al., 2012; Coumou et al., 2013). Extreme heat is a leading cause of weather-related human mortality and morbidity in many countries (Kovats and Hajat, 2008; Luber and McGeehin, 2008; Costello et al., 2009; Bi et al., 2011). Heat stress can also exacerbate vulnerabilities to other hazards (Epstein and Moran, 2006) and amplify preexisting medical conditions (Huang et al., 2011; Vardoulakis et al., 2014). While acclimatization to heat may help, it may not protect humans from unprecedented or intolerable heat stress under severe warming scenarios (Sherwood and Huber, 2010).

So far, most work-heat related research, spanning disciplines such as physiology, epidemiology and ergonomics, has concentrated on people working under physical strain, such as construction workers, farmers and soldiers, and on people working in hot environments and/or wearing heavy clothing, such as fire fighters (Xiang et al., 2014a). This kind of research has also been restricted to exploring the link between heat exposure, measured using techniques such as wet bulb globe temperature (WBGT), the heat strain model (Malchaire, 2006) or thermal work limit (TWL) (Miller and Bates, 2007), and the physical symptoms of heat stress such as heat cramps, fainting, heat exhaustion and fatigue.

Heat stress research in the workplace has also helped understand and reduce vulnerability to heat by improving social, environmental, behavioral and health care and safety advice for when exceptionally hot conditions occur (Carson et al., 2006; Akompab et al., 2013; Lao et al., 2016). There is a growing body of literature, including from Australia, relating non-climatic parameters to workplace heat stress and impacts such as higher rates of accidents (Tawatsupa et al., 2013; Xiang et al., 2014b), distortions of time perception (Tamm et al., 2014), decision quality (McMorris et al., 2006; Gaoua et al., 2011) and productivity

* Corresponding author.
E-mail address: kerstin.zander@cdu.edu.au (K.K. Zander).

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reductions (Kjellstrom et al., 2011; Sahu et al., 2013; Singh et al., 2013). Most of this research is confined to industries characterized by high ambient heat or levels of physical exertion. However, heat can cause stress without physical symptoms and can also occur among people not working in hot conditions or undertaking physical labour but who are exposed to hot weather in their daily environment (Zander et al., 2015). This suggests that there are factors other than the physical limits of core body temperature and actual heat exposure that can affect how a person copes with heat. Understanding these subclinical, largely psychological effects of heat have the potential to improve productivity and wellbeing in the same way that understanding the physical impacts of heat has decreased mortality and morbidity.

This study explores perceived heat stress of the general workforce in Australia, and specifically the factors affecting it. Understanding peoples' reported heat stress complements findings from research on actual heat exposure and symptoms of heat illness. Knowing what determines people's self-perceived heat stress is important for future adaptation. Any sign of heat stress, even as apparently trivial as feeling irritated, is important as it can already reduce people's well-being and productivity, and more severe heat stress can turn into serious heat illness. Once heat stress turns into serious adaptation capacity is compromised. It is therefore far better to address precursors of heat stress before physical stress is manifest. To the best of our knowledge, this is the first study anywhere that investigates factors affecting self-reported heat stress. The findings may improve understanding of the factors that need to be managed to support the public in dealing with increasing heat in Australia.

Our study differs from existing studies on occupational heat stress and vulnerability to heat stress/illness by asking explicitly about self-perceived heat stress over a one year time period, not during a specific heat wave, doing exercise or when working in hot environments.. Deliberately, we neither defined heat stress nor asked about different symptoms or heat illness. In so doing we acknowledged that individual responses to hot weather are likely to vary, with heat causing mild fatigue in one person inducing heat-related illness in another.

Many parts of Australia are generally hot throughout the year. Compared to the climate of recent decades, average temperatures are projected to rise by between 1.0 and 5.0 °C by 2070 and the number of heatwaves triple by 2050 (CSIRO and Bureau of Meteorology, 2014). Heat waves during summer in Australian cities are considered to have claimed more lives than any other natural disaster in the country (Coates et al., 2014). Each of the last three years (2014–2016) has set new records for heat across the country (Steffen and Fenwick, 2016) and in 2016 heat records have already been broken in the two most populated states: Victoria (9 °C above average for March; the hottest March on records ever; BoM, 2016) and New South Wales (7 °C above average for March).

2. Methods

2.1. Potential determinants of human heat stress and heat-related illness

If a person is exposed to a hot environment their level of heat stress depends on the interaction between the heat produced inside their body as a result of physical activity and the factors governing heat transfer between their body and the atmosphere (Parsons, 2009). Five factors (metabolic heat production of the body, clothing, air temperature, radiant temperature, humidity and air velocity) are usually included when calculating heat exposure in working environments (Parsons, 2009). Underlying physiological and psychological factors also influence vulnerability to heat waves (Basu, 2009; Gosling et al., 2009; Reid et al., 2009; Huang et al., 2011; Gronlund, 2014; Li et al., 2015; Table S1). These factors can be categorised into four types:

i) socio-economic and demographic (e.g. education, occupation (sector, workload), income, ethnicity),
ii) physical (illness, health and fitness, alcohol intake and smoking habits, age, gender),
iii) psychological (perceptions, experience),
iv) environmental (includes not only parameters such as temperature, humidity, rainfall and wind but also a person's location such as living/working near water, in the city or rural areas, their housing conditions such as insolation, availability of air-conditioning, and the local physical infrastructure to support heat relief).

Many of the factors are related. Older people, for instance, are more vulnerable to heat stress because they are less able to regulate and adapt their body temperature (Verbeke et al., 2001; Michelozzi et al., 2005) and they are also more susceptible to chronical illness and disabilities which may reduce their capacity to sweat and the efficiency of their cardiovascular system in distributing heat (Rowlinson et al., 2014). People of low socio-economic status and income are particularly susceptible to extreme heat events (Uejio et al., 2011; Zhang et al., 2013), for example, because they are less likely to purchase and operate air-conditioning (Gronlund, 2014).

Of the four groups, the least understood is that related to people's cognitive and psychological states (perceptions of climate change and experience of previous extreme weather events and temperature). Perceived personal experience with global warming, which is important for adaptation (Adger et al., 2007; Howe and Leiserowitz, 2013), increases certainty in the belief that global warming is happening (Spence et al., 2011; Akerlof et al., 2013; Howe and Leiserowitz, 2013) but whether this then affects the level of heat stress is unknown. It is known that the perception of temperature positively influences the concerns about climate change (Li et al., 2015) and that concerns about climate change positively influence the distress about it happening (Searle and Gow, 2010) but links between climate change concerns and heat stress as well as perceptions of temperature and heat stress are not yet well understood.

2.2. Sampling and data collection

The survey was delivered through a commissioned online survey (through MyOpinions PermissionCorp) during two waves, the first one in the first two weeks of May 2014, and the second one in the first two weeks of October 2014. Two reasons led to the choice of these two waves. First we tried to avoid very hot or cold periods across of Australia. Secondly, the replication of the same survey allowed us to compare the results and test the validity of our findings.

At the time of the survey MyOpinions had an active panel of 300,000 verified respondents which was actively managed panel in order to adhere to a strict "research only" policy governed by industry bodies such as ESOMAR, AMSRS and AMSRO. MyOpinions was also accredited to ISO 20252 and ISO 26362 to validate a commitment to professional standards and guidelines. Approximately half the panel had been recruited from a wide range of offline sources, the remainder having been recruited online. MyOpinions offered $2 to complete the survey which took 13–15 min to complete.

The sample frame consisted of panel members who were in the labourforce at the time of the survey with the age limited to between 18 and 65. The survey was conducted as follows: first, an invitation was emailed from the internet survey company to a random sample of eligible panel members (the predetermined sample frame) stratified by gender and age so that the final sample had similar proportions to the Australian labourforce population of 18 years and older. To avoid self-selection bias, panel members were not informed of the survey topic until they had agreed to complete the questionnaire. Nearly 24% of the 9,406 individuals who were contacted agreed to undertake the survey. Of these 86% (1,925) completed it.

The questionnaire had three parts:

Part 1. Demographic data (age, gender, postcode, income).

Part 2. Level of stress due to heat experienced in the previous 12 months.

Part 3. Attitudes to climate change and climate change perceptions were assessed on a four point Liker scale.

The question most relevant to heat stress was phrased as *"Do you ever feel stressed by heat when working?",* with possible responses measures on a 5-point scale from "No, never', 'Yes, but rarely', 'Yes, sometimes', 'Yes, often' and 'Yes, very often'.

We extracted data from the Bureau of Meteorology (BoM) website on the average temperature within the month of the survey of the year of the recall period and the maximum temperature on the day of the survey using respondents' postcodes linked to representative weather stations. We also used postcode date to categorize respondents' places of residence as either urban or regional/rural using the classification of the Australian Bureau of Statistics (ABS, 2012).

2.3. Analysis

Logistic regression analysis was used to estimate the individual effects of parameters on the level of respondents' heat stress using R (R Core Team, 2014). For the binary logit models[1] we coded the dependent variable as "Stressed" (coded 1) or "Not stressed" (coded 0). We therefore grouped the levels of heat stress "Never" and "Rarely" into "Not Stressed", and the other levels "Sometimes", "Often and "Very often" into "Stressed". Having checked that the variables in the separate models were not correlated, we developed a final model for each of the four types of factor that we expected to influence heat stress. Finally, including all variables, we used stepwise regression with backward and forward elimination of variables. The best model fit was found based on the models' AIC (Burnham and Anderson, 2004). Results of the two waves were compared using ANOVA.

3. Results

3.1. Description of the sample

Of the 1925 responses, 86 were omitted from the data analysis because either core questions have not been answered. In accordance with the predetermined sample request, of the remaining 1,839 respondents, about half (48%) were female (Table 1). The median age was 41 (mean: 40.9, SD: 12.4) ranging from 18 to 65. This corresponds well with the national median age of 37.3 in 2014 (ABS, 2014), given that we only included people in the labourforce aged between 18 and 65. Fifty-seven percent of respondents worked full-time, 32% part-time and 11% casual. As with many online surveys in Australia (Bambrick et al., 2009), the level of education (71% of respondents with tertiary education) was higher than the national average (59% among the 15–74 years old; ABS, 2015a).

Roughly in accordance with the population density across the country, most respondents (64.8%) were from the three most densely populated states in Australia: 25.4% from Victoria (VIC), 23.2% from New South Wales (NSW) and 16.2% from Queensland (QLD). The remaining respondents were from South Australia (SA; 8.3%), Western Australia (WA; 14.4%), Tasmania (TAS; 4.8%), Australian Capital Territory (ACT; 5.5%) and the Northern Territory (NT; 3.2%). Sixty-four percent lived in urban areas (compared to 71% nationwide; ABS, 2015b), the remaining 35% in regional or rural areas. The vast majority (96%) was from temperate climate zones and just 4% lived in northern tropical Australia.

Twenty-seven percent of respondents reported never to be stressed by heat, 26% rarely, 30% sometimes, 10% often 7% very often. For the binary dependent variables, this meant that 53% were categorized as "Not stressed" and 47% as "Stressed". The description of the sample regarding all variables used in the following models is presented in Table 1. The responses to Likert-scale questions for climate change perceptions are reported in Fig. S1 in Supplemental Materials.

Comparing results of the two survey waves (Table S2 in Supplemental Materials) showed that the percentage of people who reported being heat stressed was not significantly different across the two waves (Wave 1: 48%, Wave 2: 45%). Most of the sample characteristics also did not differ, including some core parameters such as income and age. Wave 2 had slightly more male respondents (54% in Wave 2 vs. 50% in Wave 1) and also included significantly more people with trade certificates and less with university degrees as their highest level of education. More people in Wave 2 also reported their occupation to be tradespersons or labourer and also reported slight higher physical exertion when working. In wave 1, significantly more people were employed on a casual basis with fewer in fulltime employment. Most health and behavior related parameters did not differ significantly across the two survey waves although respondents in wave 1 were significantly less likely to drink alcohol and or be regular drinkers.

Table 1
Descriptive statistics of the study sample (N =1839).

Characteristic	Metric
Age – Mean (SD)	40.9 (12.4)
Female (N, %)	886 (48%)
Physical exertion in job (1–10) – Mean (SD)	1.7 (1.2)
Time working outside (1–5) – Mean (SD)	4.6 (2.6)
Employment status	
Full-time	1055 (58%)
Part-time	664 (36%)
Not in paid job	120 (6%)
Level of education	
Year 11 or less (1)	262 (14%)
Year 12 completion (2)	269 (15%)
Diploma or trade certificate (3)	622 (34%)
University degree (4)	686 (37%)
Employee	
Public sector	415 (23%)
Private sector	1095 (59%)
Not in paid job/Self-employed[a]	329 (18%)
General health	
Poor (1)	77 (4%)
Fair (2)	371 (20%)
Good (3)	1106 (60%)
Excellent (4)	285 (16%)
Smoking habit	
Never smoked (1)	661 (55%)
Former smoker (2)	295 (24%)
Social/ irregular smoker (3)	73 (6%)
Daily light smoker 1–14 cigarettes per day) (4)	106 (9%)
Daily heavy smoker (15 cigarettes or more per day) (5)	75 (6%)
Alcohol consumption	
Never drink (1)	278 (23%)
Social drinker (2)	694 (57%)
Regular drinker (3)	238 (20%)
Exercise	
Never (1)	220 (18%)
Once or twice a week (2)	493 (41%)
3 or 4 times a week (3)	323 (27%)
About every day (4)	174 (14%)

[a] They were only a few in each of the two categories and there was not statistical significance in heat stress levels between the two. So they were grouped into one.

[1] We have also ran ordered probit models with the dependent variable coded from 0 ("Never stressed") to 5 ("Very often Stressed") but the models did not perform as good as the simpler binary logit models. We finally opted for using a series of binary models because these are more robust to errors since a mis-specification when modelling one pair of treatments will have less extensive consequences than in the simultaneous case.

Table 2
Odds ratios (OR) and 95% confidence intervals (CI) from a binary logit model with variables describing respondents' socio-economic background.

	Estimate	SE	p-value	OR	2.5% CI	97.5% CI
Intercept	1.69	0.73	0.0205			
Income (log)	−0.17	0.06	0.0091	0.85	0.75	0.96
Education: Trade certificate	0.22	0.11	0.0561	1.24	0.99	1.55
Education: Year12	0.09	0.15	0.5532	1.09	0.82	1.46
Education: Year11 and below	0.17	0.15	0.2483	1.19	0.89	1.59
Workload: Casual	−0.52	0.21	0.0122	0.59	0.39	0.89
Workload: Part-time	−0.03	0.12	0.8154	0.97	0.77	1.23
Employee: Public sector	−0.15	0.17	0.3758	0.86	0.62	1.20
Employee: Private industry	−0.16	0.14	0.2624	0.85	0.64	1.13
Occupation: Labourer / Tradesperson	0.13	0.12	0.2738	1.14	0.90	1.44

Note: Reference levels for 'Education': University degree, for 'Workload': Full-time; for 'Employee': Self-employed

3.2. Impact of socio-economic factors on reported heat stress

No correlation between the included explanatory variables exceeded 0.70 (Tables S3–S6). The log of income had a negative impact on reported heat stress ($P < 0.01$), meaning that those with lower incomes were more likely to have reported heat stress. Respondents with a trade certificate had 1.24 times greater odds of reporting heat stressed ($P < 0.1$) than those with a university degree (Table 2). People working casual hours were less likely to have reported being heat stressed ($P < 0.05$). Employee type and weather people's occupation was put down as labourers or tradespeople was not significantly associated with reported heat stress.

3.3. Impact of physical factors on reported heat stress

Gender, the level of exercise exertion and alcohol consumption did not have significant effects on reported heat stress (Table 3). Age was significant ($P < 0.05$) and positive but negative when squared ($P < 0.05$) which means that reported heat stress generally increased with age but eventually decreased.

Three variables stood out as highly significant: self-perceived health status, the degree of physical exertion while working and smoking. People with poor, fair and good self-perceived health were consistently more likely to report heat stress than people who perceived their health as excellent. People who perceived their health as poor were four times more likely to have reported heat stress ($P < 0.01$) than people with excellent health (the reference group) and people who perceived it as fair, twice as likely ($P < 0.01$). The odds of reporting heat stress increased by a factor of 1.67 for social smokers ($P < 0.05$) and by a factor of 1.81 for heavy daily smokers ($P < 0.01$), both compared to non-smokers. Daily light smokers and former smokers were as likely to have reported being heat stressed as non-smokers. People who reported higher degrees of physical exertion were more likely to have reported heat stress ($P < 0.01$).

Table 3
Odds ratios (OR) and 95% confidence intervals (CI) from a binary logit model with variables describing body functions as physical ability to cope with heat.

	Estimate	SE	p-value	OR	2.5% CI	97.5% CI
Intercept	−2.68	0.56	< 0.0001			
Age	0.05	0.03	0.0436	1.06	1.00	1.11
Age squared	−0.001	0.00	0.0255	1.00	1.00	1.00
Male	−0.09	0.10	0.3892	0.92	0.75	1.12
Health: Good	0.31	0.15	0.0360	1.36	1.02	1.81
Health: Fair	0.71	0.18	0.0001	2.04	1.44	2.88
Health: Poor	1.40	0.29	< 0.0001	4.04	2.31	7.23
Alcohol: Social	0.001	0.12	0.9958	1.00	0.79	1.27
Alcohol: Regular	0.09	0.16	0.5702	1.09	0.80	1.49
Smoking: Former	0.18	0.13	0.1457	1.20	0.94	1.54
Smoking: Social	0.51	0.23	0.0238	1.67	1.07	2.62
Smoking: Daily light	0.11	0.18	0.5545	1.12	0.78	1.60
Smoking: Daily heavy	0.59	0.22	0.0062	1.81	1.19	2.79
Exercise: Never	0.08	0.18	0.6453	1.09	0.76	1.55
Exercise: Once or twice	0.27	0.16	0.1003	1.31	0.96	1.78
Exercise: 3 or 4 times	0.18	0.16	0.2659	1.20	0.87	1.66
Physical exertion	0.21	0.02	< 0.0001	1.24	1.19	1.28

Note: Reference levels for 'Health': Excellent; for 'Smoking': Never; for 'Exercise': Every day; for 'Alcohol': Regular.

Table 4
Odds ratios (OR) and 95% confidence intervals (CI) from a binary logit model with variables describing peoples' perceptions and experiences related to climate change and heat.

	Estimate	SE	p-value	OR	2.5% CI	97.5% CI
Intercept	−1.00	0.18	0.0001			
Respondents thinking that recent heat waves have influenced their perception about climate change	0.22	0.11	0.0495	1.25	1.00	1.55
Respondents worried about climate change	0.38	0.11	0.0006	1.46	1.18	1.80
Respondents personally thinking that climate change is happening	0.01	0.13	0.9683	1.01	0.78	1.30
Respondents relating climate change to human health	0.42	0.14	0.0029	1.52	1.15	2.00
Respondents thinking that the seriousness of climate change is exaggerated	0.21	0.13	0.1002	1.23	0.96	1.57
Respondents uncertain about effects of climate change	−0.23	0.12	0.0577	0.79	0.62	1.01
Respondents doubting that scientists can confidentially predict climate change	0.14	0.12	0.2387	1.15	0.91	1.44
Respondents thinking that there is too much confusing and conflicting evidence about climate change	0.21	0.12	0.0813	1.24	0.97	1.58
Respondents perceiving the local temperature as hotter than usual on the day of the survey	0.27	0.11	0.0201	1.30	1.04	1.63
Respondents perceiving the local humidity as higher than usual on the day of the survey	0.10	0.13	0.4589	1.10	0.85	1.42

3.4. Impact of psychological factors on reported heat stress

A general belief in climate change did not have a significant impact on respondents' reported heat stress (Table 4). Those who agreed that climate change threatens human health were 52% more likely to report having felt heat stressed (OR: 1.52; $P < 0.01$) and those who felt worried about climate change 46% (OR: 1.46; $P < 0.01$). Those who thought that recent heat waves had influenced their perceptions were

Table 5
Odds ratios (OR) and 95% confidence intervals (CI) from a binary logit model with variables describing the environment where respondents lived during the survey.

	Estimate	SE	p-value	OR	2.5% CI	97.5% CI
Intercept	−1.40	0.33	< 0.0001	0.25	0.13	0.47
Max. temperature on survey day	0.004	0.01	0.7960	1.00	0.98	1.03
Max. temperature – average temperature	−0.02	0.02	0.4283	0.98	0.94	1.03
Urban areas	−0.05	0.12	0.6936	0.95	0.76	1.20
State: WA	0.76	0.29	0.0090	2.13	1.22	3.80
State: NT	0.60	0.55	0.2776	1.82	0.62	5.42
State: VIC	1.03	0.26	0.0001	2.80	1.69	4.76
State: QLD	0.43	0.31	0.1680	1.54	0.84	2.89
State: NSW	0.92	0.28	0.0009	2.51	1.47	4.38
State: SA	1.01	0.31	0.0009	2.76	1.53	5.07
State: ACT	0.39	0.33	0.2312	1.48	0.78	2.82
Tropical zone	−0.01	0.41	0.9835	0.99	0.44	2.21
Proportion of working time outside	0.28	0.04	< 0.0001	1.33	1.22	1.44

Note: Reference level for State: TAS.

25% more likely to report heat stress (OR: 0.80; $P < 0.05$).

Those who said they were uncertain about the effects of climate change were 21% less likely to report heat stress (OR: 0.79; $P < 0.1$) while those thinking that there was too much confusing and conflicting evidence about climate change were 24% more likely (OR: 1.24; $P < 0.1$).

Respondents who perceived the local temperature as hotter than usual on the day of the survey were 30% more likely to report heat stress (OR: 0.30; $P < 0.05$) while the perceived level of humidity had no significant impact.

3.5. Impact of environmental factors on reported heat stress

The state where people lived during the survey had a highly significant impact on reported heat stress. People living in VIC and SA were almost three times more likely to have reported heat stress ($P < 0.01$; Table 5), followed by people from NSW (OR: 2.51; $P < 0.01$) and WA (OR: 2.13; $P < 0.01$). People in the NT, QLD and ACT were no more likely to report heat stress than those in TAS (treated as the reference level).

The maximum mean temperature where respondents lived on survey day as well as the adjusted temperature (maximum mean temperature minus mean temperature in the month) had no significant impact on whether people had reported being heat stressed. Whether people lived in an urban or regional area and whether they lived in a tropical or temperate zone were also not significant factors.

4. Discussion

Self-reporting has an established reputation in medical research, strengthened through validation against other information sources. Thus we validated our results in two ways, an internal validation by comparing two waves of surveys, which shows no significant difference in reported heat stress. We further controlled for factors that compromise peoples' ability to cope with heat derived from the literature on heat exposure and heat vulnerability studies, such as medical conditions and factors that increases peoples' heat stress when working such as physical work and working outside. As expected (e.g. Basu, 2009; Bi et al., 2011), people with self-perceived poor and fair health were more likely to report heat stress (four and twice as likely, respectively) than people who perceived their health as excellent. Similarly, the link between smoking and heat stress is not unexpected (e.g. Raven et al., 1974), especially given that smoking reduces heat dissipation by impairing body aerobic capacity and inefficient ventilation of the lungs, and induces cardiovascular diseases such as high blood pressure which expose the individual to heat induced illness (Raven et al., 1974; Rowlinson et al., 2014). Maintaining a healthy population and minimizing smoking will be essential to reducing both clinical and subclinical impacts of higher temperatures.

As expected (e.g. Kjellstrom and Crow, 2011; Sahu et al., 2013; Tawatsupa et al., 2013), the level of physical exertion when working was positively linked with reported heat stress. This is not necessarily limited to labour jobs, as the control variable "working as labourer or tradesman" had no significant impact on reported heat stress. Whether or not people spend a high proportion of their work time outside also had no significant impact on their perceived heat stress, providing evidence that heat stress is likely to be distributed across a range of employment types.

Other factors associated with a clinical susceptibility to heat were not correlated with reported heat stress, or the relationship was complex. Thus gender differences in endocrinal physiology, body characteristics and tolerance levels (e.g. Havenith, 2005; Kenny and Olley, 2007; Witterseh et al. 2004) were not reflected in reported heat stress, consistent with the finding of Mehnert et al. (2002) who found no gender-related differences using the heat strain model. Similarly alcohol intake is known to increase heart rate and dehydration, and chronic alcohol abuse can impair the thermoregulation, all leading a higher vulnerability to heat stress (Rowlinson et al., 2014). However, we found no impact of alcohol intake, which is consistent with studies that found that people who drank more alcohol exhibited less physiological strain in heat and were more productive (Gun and Budd, 1995).

The relationship with age was complex and may have been affected by our selection of working people 18–65) as the target of our survey. Thus older people are the most vulnerable to extreme heat, partly because of pre-existing illness (e.g. Medina-Ramon et al., 2006) and reduced heat tolerance (Pandolf, 1997). Older Australians are more likely to be admitted to hospitals during heat waves than younger peers (Bi et al., 2011; Zhang et al., 2013). In our survey self-reported heat stress did increase with age but was then lower in the oldest age class. This might be because older people were less physically active, had a reduced workload or were more self-aware and realistic of potential heat-related health risks (Jia et al., 2016) so self-paced and were therefore less heat stressed. The interaction between perceived heat stress and age is complex factor and warrants more targeted research. Overall, however, the correlates of self-perceived levels of heat stress were consistent with those associated with clinical heat stress, which improves confidence in the conclusions about the sub-clinical impacts that also emerged from the survey.

4.1. Temperature and geography

It was surprising that temperature itself (at least the two parameters we could include – the maximum temperature on the survey day, and an adjusted temperature indicating whether the survey das was cooler or hotter than usual for this time of the year) did not seem to be significantly associated with reported heat stress. Another geographical factor yielding unexpected results was that, although temperatures in urban areas are usually higher than outside cities (e.g. Fischer et al., 2012; Willett and Sherwood, 2012), there were no differences in reported heat stress. However, although cites are heat islands, city people are likely to work in air-conditioning or have access to cool niches where heat impacts are less severe.

Moreover, we had expected people living in the tropical parts of Australia to be more heat stressed than those living in the temperate zone because of higher humidity. With higher humidity there is more moisture in the air reducing peoples' effectiveness of thermoregulation (Berglund and Gonzalez, 1977; Moyen et al., 2014). A recent study from Darwin in tropical northern Australia (Goldie et al., 2015) found the maximum and the mean relative humidity both to be significant predictors of hospital admission rates, besides maximum temperature. However, we could not find differences between tropical Australia which covers the northern parts of WA, the NT and QLD, and temperate Australia, despite higher annual average temperatures in the north. The reason may be that absolute temperatures are more extreme in the South (BoM, 2015; Nairn et al., 2015). Because of the constant high temperature in the tropics, people may be better adapted to heat and so less heat stressed because they already expect the weather to be hot. In temperate VIC, SA, NSW and WA, heat may be more unsettling because it fluctuates so widely. South Australia (SA), where there has been a great deal of epidemiological research on the impacts of heat (e.g. Hansen et al., 2008; Nitschke et al., 2011; Williams et al., 2012; Zhang et al., 2013; Xiang et al., 2014b; Lao et al., 2016) suffers particularly severe heat waves and, unlike the other states, has no areas that are consistently cool which may explain the higher average heat stress levels reported. Overall, we can provide evidence that reported heats stress has many more drivers beyond temperature, and that the ways in which mental and physical acclimatization affects heat stress is an area that warrants more research.

4.2. The role of perceptions

Across the whole sample almost half of the respondents reported to have been at least sometimes heat stressed when working in the year preceding the survey (i.e. 2013/2014), suggesting there is some element of choice. This element of individual choice is reflected in the finding that, while the actual temperature in places where people lived on the day they took the survey did not significantly affect reported heat stress (Table 5), how people perceived the temperature did (Table 4). Those respondents thinking that the day on which they conducted the online survey was hotter than usual were about 30% more likely to report heat stress.

Respondents who were worried about climate change, those who related climate change to human health and those who felt influenced by recent heat waves in their perception of heat stress were also more likely to report heat stress. By showing that the concern and distress is also associated with feeling stressed by hot weather, this study links the findings of Howe and Leiserowitz (2013) that those who perceive weather as being warmer than normal were more likely to believe in climate change, of Li et al. (2015) that perceptions of temperature increase concern about climate change and of Searle and Gow (2010) who found that concern about climate change is positively associated with distress about it happening. Understandably, if people are stressed by heat, for whatever reason, they also likely to be concerned at the thought of climate change raising temperatures further, increasing distress about climate change generally.

According to the notion of attribute substitution, formulated by Kahneman and Frederick (2002), heat stress is likely to exacerbate concerns about global warming. Specifically, people cannot readily determine whether global surface temperatures are rising overall but instead depend on attributes or characteristics that they feel are strongly associated with this elusive attribute or characteristic. To illustrate, they might utilize the existing ambient temperature as a proxy for global surface temperature. Consistent with this possibility, people tend to express or demonstrate greater concern with climate change when ambient temperatures are high or increasing (Joireman et al., 2010; Li et al., 2011). For example, as Li et al. (2011) showed that, on days in which the temperature was warmer than usual, participants expressed more concern about the prospect of climate change. These observations imply that heat stress could also exacerbate concerns towards climate change.

4.3. Research Outlook and study limitations

This study only begins to explore the interaction between the physiological and psychological reactions to hot weather. Temperature and other biophysical measures of heat stress reflect real biophysical limitations to human biological functioning under hot conditions within which there are limits for further improvement. There is a large gap, however, between when people start to feel bothered by heat and human physiological limits. Within this gap, this study just starts to explore the factors that explain individual variation in thermal tolerance. The work is directly equivalent to the growing understanding of pain perceptions. Here the understanding of the social and biological correlates of pain perception, such as gender (Greenspan et al., 2007) and education, which conclude that pain is 'as much a cognitive and emotional construct as a physiological experience' (Maggirias and Locker, 2002), are leading to effective pain management approaches that are sensitive to social variation (Craner et al., 2016). Similar understanding of the variation in thermal tolerance across society is likely to provide pathways for improving the capacity of individuals to cope with the increasingly hot weather anticipated.

This study was limited in a number of ways. The primary constraint lies in the potential for bias in the sampling and the need to rely on self-reported heat stress. Bias was limited to the greatest extent possible by revealing the subject of the survey only after potential respondents had agreed to complete it, though the failure of 14% to continue with the survey after its subject had been revealed could have affected the results. There are certainly biases in the sample available for invitation by MyOpinions, such as the higher level of education than is held by the community at large, despite the company's attempts to reduce this. The fact that market survey companies also use the online panels to understand consumer preferences suggests that the results are sufficiently reliable to warrant substantial investment in product development on the basis of the results. As it is, we can see no reason for this relatively minor sampling bias to have affected the results described.

Self-reported surveys are well-established in the medical literature and the biases that result well documented (e.g. Midanik, 1988; Cavanaugh et al., 2000). In this study, perceptions of heat stress can only be obtained through self-assessment procedures – it is the self-reported experience of heat as stress that is of interest with the variation across the population being the subject of analysis. Thus the self-perception is, by definition, 'correct' regardless of the physiological impact of heat on the person being stressed. Although we believe our results should be viewed cautiously, and should be used primarily to generate hypotheses for the future research which is just starting to link heat stress to cognitive and emotional issues, we doubt that the findings solely reflect biased reporting. Finally, this study is limited by its cross-sectional design: longitudinal studies are needed to evaluate further the causalities between heat tsress and other factors.

While ambient temperature is the most important contributor to physical heat strain and heat exposure models, the meteorological factors that affect perceptions of heat may be different. Further research would ideally be more fine-grained in terms of time and the meteorological variables examined with shorter recall periods and more detail about variability in not only temperature but also humidity, wind and other variables like to affect heat perception. For example, we could obtain no relevant data on humidity at the spatial and temporal scale of our survey. While relative air humidity may be very high without causing discomfort among sedentary people (Toftum et al., 1998), this can change with any exertion. Policy that can be developed from this research will therefore be greatly improved by linking broad scale population data with finer scale psychological research exploring thermal tolerance.

Finally heat stress might contribute to raising future discount rates. When uncomfortably hot, individuals naturally experience the urge to seek a cooler environment. This visceral cue is likely to orient attention to immediate needs instead of future goals, culminating in the tendency of individuals to discount the value of future rewards. People who discount the value of future rewards often abstain from healthy behaviors – behaviors that might seem unpleasant now but benefit the future (e.g. Petry, 2001; Daniel et al., 2013). With average temperatures rising and heat waves likely to increase in frequency, the potential consequences of such responses for individuals and the society also need more research.

5. Conclusions

Our exploration of demographic and geographic variation in reported (and self-perceived) heat stress across the working population of Australia shows that almost half of the respondents self-reported that they were stressed by heat at least sometimes in the year preceding the survey (Years 2013/2014). Our analysis detected no influence of standard climatic variables such as temperature and humidity on reported heat stress but many variables related to human perceptions of heat did, including the perception of the heat of the day of the survey. People who perceived the day to be hotter than usual were more likely to report heat stress. We found that factors commonly compromising body responses to heat, such as poor and fair health and heavy smoking, had the expected effect on reported heat stress. Our results were thus consistent with research on clinical symptoms of heat stress/illness, often measured in terms of heat exposure, and on vulnerability to heat and heat waves. Our results were also in line with findings from occupational health research, concluding that people with a high physical burden when working were more likely to be heat stressed. This suggests that self-perceived and reported heat stress can function as a valid proxy for vulnerability to heat stress and illness. This also suggests that the anticipated increases in frequency of hot weather could be managed by a combination of physical and behavioral responses and more social interventions that prepare people psychologically, potentially training them to cope with heat. Much can also be learnt from the 53% of the population who said they were little or not affected by heat. With heat already causing substantial reductions in productivity, an understanding of the attitudes and behaviors of those for whom heat is not currently stressful will be essential if these losses are not to increase. We conclude that understanding perceived heat stress is as important as understanding physical limits of heat for humans.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2016.10.029.

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