nature climate change

LETTERS

PUBLISHED ONLINE: 4 MAY 2015 | DOI: 10.1038/NCLIMATE2623

Heat stress causes substantial labour productivity loss in Australia

Kerstin K. Zander[1*], Wouter J. W. Botzen[2], Elspeth Oppermann[1], Tord Kjellstrom[3,4] and Stephen T. Garnett[5]

Heat stress at the workplace is an occupational health hazard that reduces labour productivity[1]. Assessment of productivity loss resulting from climate change has so far been based on physiological models of heat exposure[1]. These models suggest productivity may decrease by 11–27% by 2080 in hot regions such as Asia and the Caribbean[2], and globally by up to 20% in hot months by 2050[3]. Using an approach derived from health economics, we describe self-reported estimates of work absenteeism and reductions in work performance caused by heat in Australia during 2013/2014. We found that the annual costs were US$655 per person across a representative sample of 1,726 employed Australians. This represents an annual economic burden of around US$6.2 billion (95% CI: 5.2–7.3 billion) for the Australian workforce. This amounts to 0.33 to 0.47% of Australia's GDP. Although this was a period when many Australians experienced what is at present considered exceptional heat[4], our results suggest that adaptation measures to reduce heat effects should be adopted widely if severe economic impacts from labour productivity loss are to be avoided if heat waves become as frequent as predicted.

Climate change may have profound effects on labour productivity, although few studies have estimated its economic costs[5]. Negative impacts of hot weather include, for instance, higher work accident frequency because of concentration lapses, higher levels of fatigue and poor decision making because time perceptions change[6–8], and increased stress hormone levels which also affect cognitive performance and decision quality[9,10]. Workplace heat stress was discussed in the context of increasing heat exposure from climate change[2,11]. By the time of the latest IPCC report[12] there was strong agreement that labour productivity will decrease as a result of increases in wet bulb globe temperature (WBGT; ref. 12), which is correlated with heat stress and a need to take breaks from labour[13,14]. The only costed study of productivity impacts of heat, in Germany during 2004, estimated losses of between US$771 million and 3.4 billion for the year[15].

Correlations between WBGT and physical stress, on which these studies relied, are influenced by clothing, acclimatization and micro-environments that affect evaporative cooling[16]. Furthermore, extrapolations from physiological models to productivity changes ignore sub-clinical impacts of heat-related disorders among those who can afford to avoid working in hot weather for their livelihoods. WBGT-based models may therefore underestimate productivity loss among people who have, or can withdraw to, cool work environments even if exposed to heat away from work.

Sub-clinical effects of heat are analogous to those of other health issues, particularly chronic diseases. Just as with disease, people affected by heat can respond to hot weather either by staying home from work (absenteeism) or attending work but performing less efficiently (presenteeism; ref. 17). Taking this analogy further, we explore here the effects of heat at work on absenteeism and presenteeism using a tailored version of the work productivity and activity impairment (WPAI) questionnaire[18], which has been widely applied in health economics[19]. To the best of our knowledge this is the first time questionnaires developed to study the economic burden of diseases have been applied to heat stress. The only comparable study investigated the negative impacts of heat stress on Thai workers' propensity for injury at work[7], an indirect measure of productivity loss. Other studies of heat impact combined meteorological data with workers' compensation claims[20] or examined hospital discharge data for work-related accidents[6].

Our study is also the first to examine the costs of heat stress in Australia, a country much affected by heat[21]. Within Australia, extreme heat is the most dangerous form of natural hazard, accounting for more deaths (55%) than all other natural hazards combined, even though deaths linked to heat stress are consistently under-reported[21]. Since 1950 there has been a significant increase in the number of heat waves, both in Australia[22] and globally[23], with 2013 and 2014 breaking many records[4]. The IPCC (ref. 24) concluded that continued warming is 'virtually certain' and that there is 'high confidence' of more frequent heat extremes in Australia[25]. The IPCC also considers that heat is likely to have substantial impacts on human health in Australia and calls for more research on the socio-economic impacts of climate change, including the effects on workforce participation[24]. As Australia has a mild to hot climate, and so will receive few benefits from amelioration of cold seasons, this study concentrated on costs because increased heat is likely to have a far greater negative than positive effect on worker productivity[25].

The aims of our study were to quantify the cost of productivity loss resulting from heat stress at work, identify factors affecting productivity loss, assess which occupations were most affected, and interpret our results through the lens of health economics. Our estimates of workplace heat stress costs can be used not only to quantify the costs of unmitigated climate change and the benefits of mitigation but also to highlight the benefits of heat-stress-prevention programmes and relief strategies at work. We obtained data from an online survey in 2014 of 1,726 adults in a paid job (18 to 65) across Australia. We investigated self-reported reductions in productivity due to presenteeism and absenteeism. Presenteeism

[1]The Northern Institute, Charles Darwin University, Darwin, Northern Territories 0909, Australia. [2]Institute for Environmental Studies, VU University Amsterdam, 1081 HV Amsterdam, The Netherlands. [3]Health and Environment International Trust, Mapua 7005, New Zealand. [4]Pufendorf Institute, Lund University, 221 00 Lund, Sweden. [5]Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, Northern Territories 0909, Australia. *e-mail: kerstin.zander@cdu.edu.au

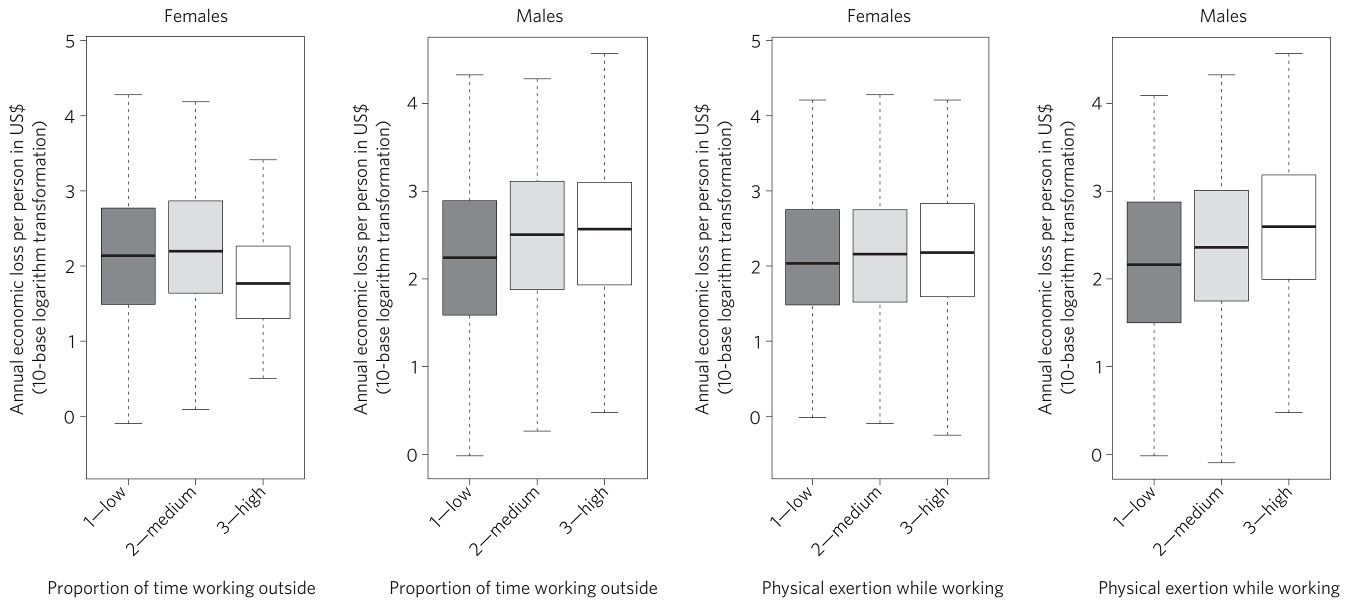

Figure 1 | Differences in annual labour productivity loss (log) for women and men in relation to the proportion of time working outside and the degree of physical exertion they experience while working.

in our study is the productivity loss from reduced intensity and/or quality of labour input due to heat; absenteeism refers to the number of days of work missed because of heat[17]. Following the approach suggested by ref. 7, we took 12 months as the recall period to avoid any seasonal heat stress bias. Although self-reported estimates need caution in their interpretation[26], the bias to which they are subject was reduced by keeping the questionnaire simple, sampling a large number of people across two sample periods (autumn and spring) and by controlling for factors known to affect productivity loss in other circumstances (see Methods).

The sample was representative in terms of gender, age, income and geographical area (Supplementary Table 1). Of the final 1,726 respondents, the majority (78%) had good or excellent health, suggesting that they had worked usual hours in the previous year.

Three-quarters ($n = 1{,}289$) of all respondents had been affected by heat at their workplace (17% of them often, 58% sometimes, 25% never; Table 1). By comparison, 50% of Thai industrial workers had at least sometimes been affected by heat stress at work[7].

About 7% ($n = 119$) of the whole sample had been absent from work owing to heat for at least one day in the previous 12 months (Table 1). On average these people were absent for 4.4 days within the previous 12 months, missing about 27 h of work. This is comparable to the number of days each year that workers in the United States were absent owing to most chronic diseases (Table 2).

Seventy per cent ($n = 1{,}214$) of all respondents said heat made them less productive on at least one day in the previous 12 months (33% of them often, 43% sometimes, 24% rarely). Consistent with other studies[27], many more people reported presenteeism than absenteeism. This means that the majority (93%) of those people stressed by heat at their workplace also experienced productivity loss due to heat.

On average these 1,214 people were 35% less productive on days on which they had suffered from heat, were less productive on ten days in the previous 12 months, and worked for 27.1 h less in that period. This is almost identical to the average hours lost from absenteeism (27.3) and slightly less than the sample's average weekly working hours (29.9). Most of the 1,214 less productive respondents (70%) reported that they were less productive on more than one day.

Taking respondents' individual income and weekly working days and hours into account, the mean productivity loss due to presenteeism for the less productive people ($n = 1{,}214$) was calculated at US$932 per person per year and the loss due to absenteeism across those absent from work owing to heat ($n = 119$) at US$845 per person per year (Table 1). This economic loss per affected person is less than that resulting from many other health issues (Table 2).

Some workers compensate for productive time lost by working longer hours. Although often ignored[28], which implies leisure time lost has no value[17], there are benefits for the employer. In this study, almost a quarter of those feeling less productive because of heat stress compensated for their lower productivity by working longer hours (Table 1). Although most (75% of those less productive) added less than an hour to their work day per less productive day, the extra 12.3 days per year made up more than 90% of the 13.3 days they lost from being less productive on hot days. Older people were more likely than young people to compensate for their less productive time (median age of those compensating: 43; median age of those not compensating: 40; $KW = 8.62$; $p = 0.0033$).

Across the whole sample, of whom 70% were less productive and 7% absent on at least one day per year owing to heat, the total economic loss was US$711 per person per year, which was reduced to US$655 if compensatory behaviour is accounted for. This was, on average, 1.2% of respondents' gross annual income. This is much higher than the estimated US$7–70 (depending on the jurisdiction) heat-related annual productivity loss per working person in Germany[15], a country much cooler than Australia. About 9.5 million Australians between 18 and 65 are employed[29]. Assuming that these people behave like those in our sample, the economic loss would be about US$6.2 billion a year (95% CI: 5.2–7.3 billion). This amounts to 0.33–0.47% of Australia's GDP of US$1,560.6 billion in 2014.

Gender and age are often correlated with absenteeism and presenteeism[30]. We found no significant correlation between age and any of the productivity-related variables but found that the median economic loss for men was higher than that for women ($KW = 5.06$, $p = 0.0245$; Table 3), partly because their median income was higher ($KW = 110.55$, $p < 0.001$). Other correlates of heat tolerance such as alcohol consumption, general health condition, level of exercise and smoking behaviour[7,31] had no significant effect on any of the productivity parameters and nor did it matter in which Australian state people lived.

Table 1 | Heat and its effects on productivity at work, self-assessed by respondents for the 12 months previous to either May or October 2014.

Characteristic	Value
Whole sample ($n=1,726$)	
Respondents stressed by heat at work	1,289 (75%)
Respondents absent from work because of heat stress	119 (7%)
Respondents less productive because of heat stress	1,214 (70%)
Respondents absent (Absenteeism; $n=119$)	
Days absent per year per person—mean (s.d.; median)	4.4 (9.4; 2.0)
Hours absent per year per person—mean (s.d.)	27.3 (63.3)
Economic loss per year per person in US$—mean (s.d.)	845 (2,222)
Respondents less productive (Presenteeism; $n=1,214$)	
% reduced productivity per person—mean (s.d.; median)	35.3 (26.0; 30)
Days per year per person with lower productivity—mean (s.d.; median)	10.0 (19.3; 4)
Hours lost per year per person—mean (s.d.)	27.1 (67.8)
Economic loss per year per person in US$—mean (s.d.)	932 (3,556)
Respondents compensating for lower productivity	289 (24%)
Respondents compensating ($n=289$)	
Days absent from work per year per person—mean (s.d.)	1.0 (5.6)
Days with lower productivity per year per person—mean (s.d.)	13.3 (20.8)
Days compensating per person—mean (s.d.)	12.3 (23.1)
Hours compensating per day per person	
Less than 30 min	101 (35%)
Between 30 and 60 min	116 (40%)
More than 60 min	72 (25%)
Total economic loss per person per year in US$ across the whole sample after accounting for compensation ($n=1,726$)—mean (s.d.; median)	655 (2,634; 47)
Total costs for the Australian workforce ($n=9,547,390$) in US$	6.2 billion

Monetary values are in US$(AU$1 ~ US$0.9; October 2014).

Table 2 | Comparison of productivity loss estimates resulting from different causes.

Cause	Country	Presenteeism	Absenteeism	Reference
Paid work days with lower productivity per affected person per year				
Chronic rhinosinusitis	US	38.8	24.6	Rudmik *et al.*[36]
Depression	US	35.7	8.3	Stewart *et al.*[37]
Migraine	US	4.9	3.2	Burton *et al.*[38]
Migraine	US	69.6		Osterhaus *et al.*[39]
Migraine	UK	4.5	2	Cull *et al.*[40]
Heat	Australia	10.0	4.4	This study
Paid work productivity loss per affected person per year (in US$)				
Chronic rhinosinusitis	US	8,150		Rudmik *et al.*[36]
Back pain	UK	5,870		Maniadakis and Gray[28]
Migraine	US	3,199–10,844*		Serrano *et al.*[41]
Migraine	US	400		Edmeads *et al.*[42]
Social anxiety disorder	Germany	9,200		Stuhldreher *et al.*[43]
Smoking	US	1,807		Bunn *et al.*[44]
Insomnia	US	1,863		Rosekind *et al.*[45]
Insufficient sleep	US	1,503		Rosekind *et al.*[45]
Heat	Australia	931		This study[†]

References are provided in Supplementary Methods. *Depending on gender and age; [†]with compensation adjustment (see Table 1).

Productivity loss was most strongly correlated with the physical burden of respondents' jobs (Table 3). Economic loss from reduced productivity increased as physical exertion increased, particularly for men (Fig. 1). Whereas, among men, productivity loss was positively correlated with the proportion of time spent working outside, location of work had no discernible effect on women. However, men were three times more likely than women to spend a high proportion of their working time outside.

Surprisingly, about half of the annual productivity loss could be attributed to people who were spending little of their working time outside. The most expensive loss was among managers (US$1,566; Supplementary Table 2). Clerical and administrative and sales workers had the lowest annual productivity losses. Clerical and administrative workers also had significantly fewer productivity affected days than any other occupation. So, although people in leading positions might not lose as many hours per year owing to

Table 3 | Differences in median values of productivity-related parameters, calculated for respondents less productive due to heat stress ($n = 1,214$).

	Response variable		
Effects	Days less productive	%-level of productivity loss	Annual total productivity loss
Age	Not significant	Not significant	Not significant
Gender			
Male	5	30	220*
Female	4	30	119*
Proportion of time working outside			
Low (less than 10%)	4	26**	139**
Medium (up to 50%)	5	34	216**
High (more than 50%)	5	32**	178**
Physical exertion while working			
Low	3*	22*	108*
Medium	5	31*	158*
High	5	43*	273*
Occupation			
Cleric/administrative workers	2**	29	124
Community/personal service workers	5	39	136
Labourers	5	31	198
Machinery operator/drivers	5	35	389
Manager	3	26	184
Professionals	4	29	200
Sales workers	5	27	119
Technicians/trades workers	5	31	295
State			
Australian Capital Territory	3	25	131
New South Wales	4	34	202
Northern Territory	5	22	334
Queensland	5	27	161
South Australia	5	39	246
Tasmania	2	18	90
Victoria	4	32	133
Western Australia	5	25	155

Annual total productivity loss is adjusted for compensation and in US$. Significance codes: * = 1%, ** = 5%.

heat stress, the hours they lose are more costly to their employers. We do not know the reason for the unexpectedly high productivity loss among people working inside but note that productivity losses from migraines were greatest when onset occurred during normal sleep hours before work[32], and suggest that hot sleepless nights may reduce productivity the following day.

There are many ways to manage heat stress at work, including developing regional thresholds for workplace heat management[33], optimizing work patterns to minimize heat stress[34], encouragement of self-pacing[13] and reductions in heat exposure, improved access to hydration, acclimatization and fitness programmes and a reorientation of attitudes towards working in the heat among both employees and employers[31]. The results also suggest that it may be advantageous for employers to implement strategies that help employees manage heat impacts away from work[35], but there is far less research in this area. More research is also needed to understand the drivers underlying the impacts of hot weather on presenteeism and absenteeism using studies over shorter time periods, tailor strategies to workplaces and employment type, refine work loss compensation strategies, understand costs of heat on unpaid work and to manage heat during leisure time where there is little understanding of appropriate heat management[21]. Finally, we recommend the development and use of a standardized questionnaire to understand heat-related work productivity losses similar to those developed for many diseases.

Methods

Methods and any associated references are available in the online version of the paper.

Received 20 December 2014; accepted 24 March 2015; published online 4 May 2015

References

1. Parsons, K. *Human Thermal Environments* (CRC Press, 2014).
2. Kjellstrom, T., Kovats, R. S., Lloyd, S. J., Holt, T. & Tol, R. S. J. The direct impact of climate change on regional labor productivity. *Arch. Environ. Occup. Health* **64,** 217–227 (2009).
3. Dunne, J. P., Stouffer, R. J. & John, J. G. Reductions in labour capacity from heat stress under climate warming. *Nature Clim. Change* **3,** 563–566 (2013).
4. *Special Climate Statements* (Bureau of Meteorology, accessed December 2014); http://www.bom.gov.au/climate/current/statements
5. Stern, N. The structure of economic modeling of the potential impacts of climate change: Grafting gross underestimation of risk onto already narrow science models. *J. Econ. Lit.* **51,** 838–859 (2013).
6. Morabito, M., Cecchi, L., Crisci, A., Modesti, P. A. & Orlandini, S. Relationship between work-related accidents and hot weather conditions in Tuscany (central Italy). *Ind. Health* **44,** 458–464 (2006).

7. Tawatsupa, B. *et al.* Association between heat stress and occupational injury among Thai workers: Findings of the Thai cohort study. *Ind. Health* **51,** 34–46 (2013).
8. Tamm, M. *et al.* The compression of perceived time in a hot environment depends on physiological and psychological factors. *Q. J. Exp. Psychol.* **67,** 197–208 (2014).
9. McMorris, T. *et al.* Heat stress, plasma concentrations of adrenaline, noradrenaline, 5-hydroxytryptamine and cortisol, mood state and cognitive performance. *Int. J. Psychophysiol.* **61,** 204–215 (2006).
10. Gaoua, N., Racinais, S., Grantham, J. & El Massioui, F. Alterations in cognitive performance during passive hyperthermia are task dependent. *Int. J. Hyperthermia* **27,** 1–9 (2011).
11. Kjellstrom, T., Gabrysch, S., Lemke, B. & Dear, K. The 'Hothaps' programme for assessing climate change impacts on occupational health and productivity: An invitation to carry out field studies. *Glob. Health Action* **2,** http://dx.doi.org/10.3402/gha.v2i0.2082 (2009).
12. Smith, K. R. *et al.* in *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (eds Field, C. B. *et al.*) 709–754 (IPCC, Cambridge Univ. Press, 2014).
13. Miller, V., Bates, G., Schneider, J. D. & Thomsen, J. Self-pacing as a protective mechanism against the effects of heat stress. *Ann. Occup. Hyg.* **55,** 548–555 (2011).
14. Sahu, S., Sett, M. & Kjellstrom, T. Heat exposure, cardiovascular stress and work productivity in rice harvesters in India: Implications for a climate change future. *Ind. Health* **51,** 424–431 (2013).
15. Hübler, M., Klepper, G. & Peterson, S. Costs of climate change—the effects of rising temperatures on health and productivity in Germany. *Ecol. Econ.* **68,** 381–393 (2008).
16. Budd, G. M. Wet-bulb globe temperature (WBGT)—its history and its limitations. *J. Sci. Med. Sport* **11,** 20–32 (2008).
17. Zhang, W., Bansback, N. & Anis, A. H. Measuring and valuing productivity loss due to poor health: A critical review. *Soc. Sci. Med.* **72,** 185–192 (2011).
18. Reilly, M. C., Zbrozek, A. S. & Dukes, E. M. The validity and reproducibility of a work productivity and activity impairment instrument. *Pharmacoeconomics* **4,** 353–365 (1993).
19. Lofland, J. H., Pizzi, L. & Frick, K. D. A review of health-related workplace productivity loss instruments. *Pharmacoeconomics* **22,** 165–184 (2004).
20. Xiang, J., Bi, P., Pisaniello, D. & Hansen, A. The impact of heatwaves on workers, health and safety in Adelaide, South Australia. *Environ. Res.* **133,** 90–95 (2014).
21. Coates, L., Haynes, K., O'Brien, J., McAneney, J. & de Oliveira, F. D. Exploring 167 years of vulnerability: An examination of extreme heat events in Australia 1844–2010. *Environ. Sci. Policy* **42,** 33–44 (2014).
22. Alexander, L. V. & Arblaster, J. M. Assessing trends in observed and modelled climate extremes over Australia in relation to future projections. *Int. J. Climatol.* **29,** 417–435 (2009).
23. Perkins, S. E., Alexander, L. V. & Nairn, J. R. Increasing frequency, intensity and duration of observed global heatwaves and warm spells. *Geophys. Res. Lett.* **39,** L20714 (2012).
24. Reisinger, A. *et al.* in *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (eds Field, C. B. *et al.*) 1371–1438 (IPCC, Cambridge Univ. Press, 2014).
25. Zivin, J. G. & Neidell, M. Temperature and the allocation of time: Implications for climate change. *J. Labor Econ.* **32,** 1–26 (2014).
26. Stone, A. A., Bachrach, C. A., Jobe, J. B., Kurtzman, H. S. & Cain, V. S. (eds) *The Science of Self-Report: Implications for Research and Practice* (Lawrence Erlbaum Associates, 1999).
27. Li, X., Gignac, M. A. M. & Anis, A. H. The indirect costs of arthritis resulting from unemployment, reduced performance, and occupational changes while at work. *Med. Care* **44,** 304–310 (2006).
28. Maniadakis, N. & Gray, A. The economic burden of back pain in the UK. *Pain* **84,** 95–103 (2000).
29. Australian Bureau of Statistics (ABS) *2011 Census of Population and Housing* (Commonwealth of Australia, 2012).
30. Ng, T. W. H. & Feldman, D. C. The relationship of age to ten dimensions of job performance. *J. Appl. Psychol.* **93,** 392–423 (2008).
31. Singh, S., Hanna, E. G. & Kjellstrom, T. Working in Australia's heat: Health promotion concerns for health and productivity. *Health Promot. Int.* http://dx.doi.org/10.1093/heapro/dat027 (2013).
32. Landy, S. H., Runken, M. C., Bell, C. F., Higbie, R. L. & Haskins, L. S. Assessing the impact of migraine onset on work productivity. *J. Occup. Environ. Med.* **53,** 74–81 (2011).
33. Rowlinson, S., YunyanJia, A., Li, B. & ChuanjingJu, C. Management of climatic heat stress risk in construction: A review of practices, methodologies, and future research. *Accid. Anal. Prev.* **66,** 187–198 (2014).
34. Yi, W. & Chan, A. Optimal work pattern for construction workers in hot weather: A case study in Hong Kong. *J. Comput. Civ. Eng.* http://dx.doi.org/10.1061/(ASCE)CP.1943-5487.0000419 (2014).
35. Kamerman, S. B. & Kahn, A. J. *The Responsive Workplace: Employers and a Changing Labor Force* (Columbia Univ. Press, 2013).
36. Rudmik, L. *et al.* Productivity costs in patients with refractory chronic rhinosinusitis. *Laryngoscope* http://dx.doi.org/10.1002/lary.24630 (2014).
37. Stewart, W. F., Ricci, J. A., Chee, E., Hahn, S. R. & Morganstein, D. Cost of lost productive work time among US workers with depression. *J. Am. Med. Assoc.* **289,** 3135–3144 (2003).
38. Burton, W. N., Conti, D. J., Chen, C-Y., Schultz, A. B. & Edington, D. W. The economic burden of lost productivity due to migraine headache: A specific worksite analysis. *JOEM* **44,** 523–529 (2002).
39. Osterhaus, J., Gutterman, D. & Plachetka, J. Healthcare resource and lost labour costs of migraine headache in the US. *PharmacoEconomics* **2,** 67–76 (1992).
40. Cull, R. E., Wells, N. E. J. & Miocevich, M. L. The conomic cost of migraine. *Br. J. Med. Econ.* **2,** 103–115 (1992).
41. Serrano, D. *et al.* Cost and predictors of lost productive time in chronic migraine and episodic migraine: Results from the American Migraine Prevalence and Prevention (AMPP) study. *Value Health* **16,** 31–38 (2013).
42. Edmeads, J. & Mackell, J. A. The economic impact of migraine: An analysis of direct and indirect costs. *Headache* **42,** 501–509 (2002).
43. Stuhldreher, N. *et al.* The costs of social anxiety disorder: The role of symptom severity and comorbidities. *J. Affect. Disord.* **165,** 87–94 (2014).
44. Bunn, W. B., Stave, G. M., Downs, K. E., Alvir, J. M. & Dirani, R. Effect of smoking status on productivity loss. *J. Occup. Environ. Med.* **48,** 1099–1108 (2006).
45. Rosekind, M. R. *et al.* The cost of poor sleep: workplace productivity loss and associated costs. *J. Occup. Env. Med.* **52,** 91–98 (2010).

Acknowledgements
The project was funded from two internal research grants from the Faculty of Law, Education, Business and Arts (LEBA) at Charles Darwin University.

Author contributions
K.K.Z., E.O. and S.T.G. designed the survey. K.K.Z. analysed the data and wrote the first version of the manuscript with the help of S.T.G. W.J.W.B. helped interpret the data and results and provided technical and conceptual advice. T.K. provided conceptual advice. All authors contributed to improving and revising the paper.

Additional information
Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to K.K.Z.

Competing financial interests
The authors declare no competing financial interests.

Methods

Survey instrument. The survey was delivered through a commissioned online survey in the first two weeks of May 2014. The study was approved by the Charles Darwin University Human Research Ethics Committee (H13119). The sample was drawn from an online panel recruited by MyOpinions PermissionCorp. MyOpinions has an active panel of 300,000 verified respondents. MyOpinions has developed, and continues to maintain, an actively managed panel which adheres to a strict 'research only' policy governed by industry bodies such as ESOMAR, AMSRS and AMSRO. MyOpinions is also accredited to ISO 20252 and ISO 26362 professional standards and guidelines. Approximately half of the panel has been recruited from offline sources. Depending of the length of the survey, MyOpinions offers small incentives in the range of AUD 2–6 for completion of a survey.

Data. Our data were obtained from the MyOpinions panel, from which a random sample of adults (between 18 and 65 years) in paid employment was drawn so that it was representative of the Australian population in terms of gender, age and geographical distribution. To avoid very hot periods and to minimize bias that could arise from recent experience of heat waves, we conducted the survey in two periods, one in early May (Austral autumn), the other in early October 2014 (Austral spring). A total of 2,193 people were sampled (994 in the first wave and 1,199 in the second wave) with 1,736 people completing the survey (79%). The average time to complete was 13.2 min. Those who needed less than 7 min were deleted ($n=2$). Entries of respondents who were absent from work owing to illness for more than 150 days a year were also deleted ($n=4$) as were those claiming an annual income >AUD 1,000,000 ($n=4$). The final data set included 1,726 people.

The questionnaire. The questionnaire consisted of two parts. The first part was about peoples' work (occupation, sector of employment, employer, income, weekly working hours, proportion of time working outside (low = less than 10%, medium = up to 50%, high = more than 50%) and physical exertion while working). Physical exertion while working was asked as a scale question from 1 to 10, 1 meaning that the physical burden of work is very low, and 10 meaning that it is very high. The variable was transformed into three categories: low (scores 1–3), medium (scores 4–7) and high (scores 8–10).

At the end of this first part we asked two trigger questions on the impact of heat on respondent's work. First, if respondents answered positively to having been stressed by heat at work in the previous 12 months, they were asked to identify the number of work days missed (absenteeism) and the number of days they went to work but were less productive because of heat stress (presenteeism). Second, if respondents said that they had been at work but were less productive because of heat stress on at least one day in the past 12 months, they were asked about the extent to which their work had been impaired, expressed as the percentage impairment due to heat stress. These questions were taken from the work productivity and activity impairment (WPAI) questionnaire[18] used in health economics and modified to our purpose. One modification was that, following the approach of ref. 7, we used a recall period of 12 months instead of a recall period of seven days. Those respondents who had been less productive because of heat stress were then asked if they compensated for the productivity loss by working longer hours and, if so, on how many of the less productive days they compensated for lost time and for how many more hours they then worked (less than 30 min, between 30 and 60 min, more than 60 min).

The second part of the questionnaire was presented to all respondents and included questions about their demographic background (gender, age, education, postcode, nationality) and lifestyle (health status, smoking behaviour, alcohol consumption, level of exercise).

Calculation of production loss. Total production loss (TPL) was calculated as TPL = PLA + PLP, where PLA is the annual production loss from absenteeism and PLP the annual production loss from presenteeism.

PLA was calculated for each individual as NA*DI where NA = number of days absent per year due to heat stress and DI = daily income. Daily income was derived from respondents' stated annual gross income. We assumed 250 working days per year and a 5-day working week. For those working full time we assumed 38 h/week, for part-time workers 19 h/week. Those who did not fall into the full- and part-time employment categories stated their actual weekly working hours.

PLP was calculated for each individual as HL*NP*HI, where HL = hr lost per less productive day, NP = number of d yr^{-1} of lower productivity and HI = hourly income. HL was calculated as $p{*}H$ where p = the percentage by which productivity was reduced on less productive days and H = number of hours per day spent working for payment.

Statistical analysis. The *R* statistical package (version 2.15.3) was used to carry out statistical tests on the effect of various socio-economic, lifestyle and employment characteristics of respondents (see Table 1) on the number of days absent and present but less productive, on the level of reduced productivity, on the economic loss as a result of absenteeism and presenteeism, and on the annual total economic loss. Because the relevant parameters were not normally distributed, we applied non-parametric Kruskal–Wallis (KW) tests, followed by multiple comparison tests (equivalent to Tukey HSD) using the command kruskalmc in the *R* library pgirmess.

Survey limitations. Self-reported estimates are subject to both random and systematic bias[26]. Although unable to remove all bias, we attempted to reduce and/or manage it in four ways. First, bias is increased by complexity[46], but our questionnaire, like the medical models on which it was based[18], was relatively simple. Second, we had a substantial sample size of 1,726 respondents spread evenly across two sample periods. Third, although neither of the two periods (May and October 2014, Austral autumn and spring respectively) was likely to be subject to absolute temperature extremes that could have influenced an immediate response, for one group summer had occurred within the previous six months, whereas for the other group summer was in the first half of the 12-month recall period. However, the responses of the two groups were statistically indistinguishable (apart from an extra day, on average, absent owing to illness), as were the characteristics of those sampled (Supplementary Table 3), suggesting that the survey period (May or October) did not cause undue bias. Finally, presenteeism and absenteeism in response to heat stress was broadly comparable to that in other health issues, particularly chronic diseases (Table 2). Similarly, we found that the self-stated percentage productivity loss in our study closely resembled those stated in other studies. Another way of managing bias is to control for causal inferences. In our study we tested for the influence of factors known to affect productivity loss in other circumstances (for example, proportion of time working outside and physical exertion), and the results were as expected.

Another potential limitation was that the sampled year proved to have had record-breaking heat over a large proportion of the country during the Australian summer[4]. Although this may have caused people to have strong recollections of heat in the previous 12 months, the predictions of ongoing increases in average temperatures and heat wave frequency in Australia[22] suggests that the conditions during 2013/14 may not be exceptional for long and that their consequences should be incorporated into heat management planning. However, the conclusions could be strengthened by repeating the survey over multiple years.

Last the study could have been strengthened by deeper analysis of the causes of presenteeism and absenteeism and the interactions with disease, sleep disruption or other mental/emotional impacts.

References

46. Ainsworth, B. E. *et al.* Recommendations to improve the accuracy of estimates of physical activity derived from self report. *J. Phys. Act. Health* **9,** 76–84 (2012).