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An Evaluation of Two Exceptional Heat Events: The Effects of a Heat Warning System in Adelaide, South Australia.

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ABSTRACT

Background Heatwave warning systems aim to assist in reducing health effects during extreme heat. Evaluations of such systems have been limited. This study explored the effect on morbidity and mortality of a heatwave warning program in Adelaide, South Australia, by comparing extreme events in 2009 and 2014, the latter with exposure to the preventive program.

Methods The health outcomes during the two heatwaves were compared using the incidence rate ratios of daily ambulance callouts, emergency presentations and mortality data during the heatwaves compared to non-heatwave periods during the warm seasons. Excess or reduced numbers of cases were calculated and the differences in cases between the two heatwaves were estimated.

Results Incidence rate ratios for total ambulance call-outs and emergency presentations were lower during the 2014 heatwaves compared to the 2009 event. The estimated differences in health- specific outcomes between 2009 and 2014 were statistically significant with -207 (59%) for cardiac-related call outs, -134 (30%) for renal and -145 (56%) for heat-related emergency presentations. Mortality was not reduced in 2014. There were an estimated 34.5 excess deaths in 2009 and 38.2 in 2014.

Conclusion Morbidity outcomes were reduced significantly during the 2014 event. The fact that cardiac, renal and heat-related diagnoses were significantly reduced is likely to be associated with the intervention in 2014, which comprised not only a public warning through media, but also intense preventive measures directed to individual populations at risk. Further analysis of risk factors of mortality during heatwaves should be explored.

Strength and Limitations of this study

- Heatwave warning systems based on defined temperature triggers and adaptive public health measures have been implemented in many cities, but the evaluation of the effectiveness of these systems is limited to mortality.
- This study utilised morbidity and mortality data from two extreme heatwave periods, before and after the introduction of a heatwave warning system in Adelaide, South Australia, to compare the impact.
- There are limitations in conclusively evaluating the effects of a population-based heat health intervention. It could be argued that improvements in health outcomes could be due to adaptation to heat or that it is difficult to compare heatwave events.
- Significant morbidity reductions were observed suggesting that preventive measures contributed to this success. As this was not the case for mortality,

further efforts have to be made to explore the reduction of risk factors for mortality during heatwaves.

- Evaluation of interventions is an iterative process and should be used continuously alongside fine tuning of the intervention measures using evidence –based research.

INTRODUCTION

Health effects during extreme heat should be largely preventable. However, during recent heat events worldwide and in Australia, significant increases in morbidity and mortality have been evident. A systematic analysis of health effects during heatwaves (3 or more days of maximum temperature ≥ 35°C) for Adelaide, the capital of South Australia (SA) (1993-2006) indicated morbidity incidence above what is normally expected during summer periods, but did not show any increases in mortality.[1] This changed when a record breaking 13 day heatwave occurred in summer 2009 during which mortality increased by 37% in the 15-64 age groups together with large increases in renal, ischaemic heart disease and direct heat-related morbidity.[2]

This unparalleled event evoked the need for a heat warning system (HWS) for metropolitan Adelaide's 1.30 million residents, 76.9% of the total SA population, considering the predictions of an increased frequency of extreme heatwaves under the climate change scenario for SA. A HWS was introduced in November 2009, following the extreme heatwave in January and February 2009. These systems are now in place in many cities of the world.

Several HWSs in the United States were initiated in response to extreme heatwaves[3-4]. Since the 2003 heatwave in Europe, HWSs have been also rolled out for many European cities.[5-6] Only recently, the World Health Organisation (WHO) in conjunction with the World Meteorological Organisation (WMO) published a guidance document on the development of HWSs.[7] The Adelaide HWS addresses most of the pertinent elements presented in the WHO/WMO framework including a definition of the event, an across the government agreed division of roles and responsibilities to reduce possible health effects among those at risk, and a communications strategy to engage with the general population. The process of establishing a HWS in Adelaide has been described in a recent qualitative study outlining the collaborative stakeholder engagement process by the state government.[8]

Another key factor mentioned in the WHO/WMO framework is the need to evaluate the success of the health warnings; whether it has offered health protection verified by a reduction of cases of heat-related illnesses compared to what was expected from previous events, or in terms of public recall of information, and whether the warning changed the behaviour of people at risk.[7] Evaluating heat warning interventions has been the subject of two recent reviews.[9-10] They concur that the limited intervention studies present indicated positive results. Most of the studies were limited to the evaluation of mortality. Evaluations of impacts were hampered by the fact that subsequent heatwaves had different intensities and durations.[10-11]

In summer of 2014, the Adelaide extreme heat warning system was twice activated within a one month period, and when combined these two heatwave periods resembled in duration and intensity the 2009 heat event. This provided a timely opportunity to compare health outcomes during those events as part of an evaluation of the effectiveness of the heat health intervention in Adelaide.

METHODS

The study is of ecological design comparing morbidity and mortality of two extreme heatwaves at the population level.

Health data

Morbidity and mortality data for metropolitan Adelaide for the warm seasons (October-March) from 1993 to 2014 were obtained from The Department for Health and Ageing. For comparison purposes, the specific health outcome categories chosen for analysis were those that were significantly increased during the 2009 heatwave. Ambulance callout data were obtained from SA Ambulance Service.

The following International Classification of Disease (ICD-10) categories of diseases were selected for emergency department presentations (hospital admissions data was also obtained and the results can be seen in the appendix online): renal (ICD-10 N00-N399) and direct heat-related (ICD-10, E86, T67, X30). The pre-defined categories provided by SA Ambulance Service for call-outs were used. Only total mortality data were used as cause-specific data for 2014 were unavailable.

Heat health interventions

Table 1 summarises the elements of Adelaide's short-term interventions during extreme heat warning episodes.

The HWS has an all-government approach with the State Emergency Service (SES) as the 'Hazard Leader'.[12] It is triggered in conjunction with the Bureau of Meteorology (BOM) when an average daily temperature of ≥32ºC is forecast (average of daily maximum and minimum = ADT) for three or more days. This temperature threshold is based on retrospective analysis of health and temperature data[13-14]. Upon reaching the threshold, the government activates heat-related interventions to the specific needs of vulnerable populations. For example, all people who access one or more social services are monitored regarding their wellbeing. The general public is warned, informed and educated through media announcements.

The Australian Red Cross operates an important free service in collaboration with the state government, specifically directed to people at risk. Those who have been registered are contacted on a daily basis during the warning period. Carers, doctors, friends and family members can enrol a person in this system based on a vulnerability assessment tool.[15]

Pre-season work is invested into re-assessing extreme heat plans and intervention measures based on ongoing risk factors research.[16-18]

Lead agencies	Triggers/threshold	Interventions	

SA State Emergency Service (SES) is advised by Bureau of Meteorology (BOM). SES informs other agencies with one lead day.	3 day rolling forecast of daily average (minimum and maximum temperatures divided by two) temperatures (ADT)
	
	Threshold for an extreme heat warning is reached when ADT is 32C or above (e.g. 40C daytime and 24C night time)
		Before/start of summer and ongoing:
		• General heat health advice before summer.
		• Heat plan review of all relevant government and non-government agencies.
		• Meeting of all agencies before the summer
			During the alert:
			
			• Activation of specific and co-ordinated extreme heat plans (Local government, state government and non-government), see examples:
			  • Public alerts and advice through media
			  • Continuous review of emergency, ambulance and other

		season to discuss co-ordination issues. • Collaborative Research agenda	clinical response capabilities in the health sector. • Australian Red Cross provision of free support calls to registered vulnerable people.

Table 1: Extreme heat warning in Adelaide, South Australia: description of the program and interventions.

Temperature data

Temperature data were obtained from a BOM weather station which is representative of the metropolitan area of Adelaide.

The definition (3 or more days of ≥35ºC) for heatwave impact assessments in Adelaide was used to compare the health impacts during the 2014 heatwaves to those in 2009[1-2]. The 2009 heatwave (hw2009) (26 January to 7 February) lasted 13 days with an average maximum temperature of 41°C and an average minimum temperature of 26.1°C. The 2014 heatwave (hw2014) is a composite of two heatwaves with only 9 days in between (12 January to 17 January and 27 January to 2 February 2014). Each of the events (hw2009 and hw2014) included one day below 35°C. The average maximum temperature during the first component of the hw2014 was 42.2°C and the minimum was 24.8; for the second composite period it was 39.4 and 21.5 accordingly. During both hw2014 periods, extreme heat warnings were triggered. Table 1 in the online appendix shows the temperature constellation for the 2009 and 2014 heatwaves in more details.

Statistics

To compare health impacts, a case series analysis was used.[19] Average daily rates of adverse health outcomes during the defined heatwaves were compared with non-heatwave periods during the respective warm seasons. The rate ratios of incidences of health outcomes during 'case' and 'control' periods were expressed as incidence rate ratios (IRR).

The analysis was conducted within years, therefore implicitly adjusting for long-term trends for the years 1993-2014.[20] To calculate the IRR, poisson regression models were fitted using the statistical software package Stata version 13.[21] Each model was tested for fit, and negative binomial regression models were used to allow for over-dispersion if required. To assess the impact of the intervention, the statistical significance of the difference between the 2009 and 2014 IRRs were estimated using the post estimation command 'lincom' in Stata. Furthermore, expected cases were calculated from the total of the observed cases (N) during the respective heatwave period divided by the IRR of the relevant health outcome. Excess (or reduced) cases were obtained by subtracting expected from observed cases [N – (N/IRR)]. The difference between excess cases in 2009 and 2014 provided an indicator of effectiveness of the intervention. Standard errors were manipulated using the formulae provided in Hansen et al to produce a 95% confidence interval (CI) for the estimates of the excess/reduction and the difference in cases between the 2009 and 2014 events (see appendix for formulae).[22]

RESULTS

Table 2 provides summary statistics for daily average health outcomes during the two comparison heatwave and non-heatwave periods in 2009 and 2014. Ambulance call-outs during the hw2009 and hw2014 were higher compared to their respective non-heatwave periods. Unlike in the hw2009 when average daily hospital and emergency presentations were higher than during the respective non-heatwave periods, this was reversed in the hw2014. As in 2009, average mortality was higher during the heatwave compared to the non-heatwave days in 2014.

Table 2 Descriptive statistics for total daily health outcomes for summer 2008/9 and 2013/14 (October to March), for the two defined heatwaves (hw) (13 days) and non-heat wave periods(169 days): minimum, maximum, mean and standard deviation of daily incidences of ambulance call-outs, hospital admissions, emergency presentations and mortality.

Description	Min.	Max.	Mean	SD.
Ambulance call-outs				
hw 2009: 13 days	243	361	291.1	36.1
Non-hw periods in 2009 169 days	187	301	249.5	20.1
hw 2014: 13 days	306	392	342.9	25.4
Non-hw periods 2014 169 days	258	391	326.4	25.0
Hospital admissions				
hw 2009	460	1742	1322.9	506.4
Non-hw periods 2009	271	1798	1231.5	523.4
hw 2014	399	1713	1300.0	528.8
Non-hw periods 2014	334	1972	1311.7	553.9
Emergency department presentations				
hw 2009	905	1065	994.5	54.3
Non-hw periods 2009	802	1122	971.5	59.0
hw 2014	918	1139	999.9	55.7
Non-hw periods 2014	915	1209	1034.3	66.4
Mortality				
hw 2009	15	44	28.6	9.4
Non-hw periods 2009	14	41	26.1	5.6
hw 2014	21	34	28.0	4.1
Non-hw periods 2014	15	38	25.3	4.7

Ambulance call-outs

Table 3 shows the IRRs for ambulance call-outs during heatwaves compared to non-heatwave periods in 2009 and 2014. In 2009, the incidence of total ambulance call-outs increased by 16% over non-heatwaves in the warm season. Compared to hw2009, total call-outs were decreased during hw2014, with the 2014 point estimate indicating a non-significant 5% increase over non-heatwave periods. Reductions compared to hw2009 were also evident across all age groups.

Total and age-related cardiac-related call-outs in 2014 showed a protective effect during the heatwaves compared to the non-heatwave periods. In 2009 the reverse occurred.

Comparing 2014 and 2009

Comparing IRRs indicated significant reductions in all-age total and cardiac-related call-outs occurring in 2014. Age specific differences were manifest in the 75+ age group for total call-outs and for cardiac call-outs in all adult age groups.

There were 220 excess ambulance call-outs estimated during the hw2014 compared to 518 in the hw2009 (table 3). Fifty nine excess cardiac-related call-outs were estimated for the 2009 heatwave; in 2014, a significant reduction of 148 cardiac-related call-outs was assessed. Based on these estimates there were 297 (9%) fewer total call-outs and 207 (59%) fewer cardiac-related call-outs during the hw2014 than the hw2009 outcomes.

Table 3: Ambulance call-outs IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of ambulance call-outs during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. Excess or reduction of ambulance call-outs during the 2009 and the 2014 heatwaves and comparison between 2009 and 2014 (Expected cases = observed cases divided by the IRR; Excess/reduced cases = observed cases-expected cases; comparison between 2009 and 2014= excess/reduced 2014 cases–2009 excess/reduced cases)
*Empty cells indicate insufficient data to produce reliable estimates. **P<0.001; * p<0.05; #p<0.1*

Ambulance Call-outs									
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases IRR (95% CI)	Excess/ Reduction (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	**1.16** (1.09-1.24)**	1.08 (0.90-1.29)	0.86 (0.64-1.15)	***1.14 (1.04-1.24)**	***1.11 (1.01-1.23)**	****1.24 (1.17-1.33)**	3760	**517.5 (308.2, 726.8)**	-297.3# (-644.4, 49.8)
total 2014	1.05 0.99-1.12	0.90 0.75-1.08	0.83 0.64-1.09	#1.09 1.00-1.19	1.06 0.97-1.15	1.04 0.98-1.11	4457	220.2 (-56.7, 497.1)	
2014:2009	**0.91* 0.83-0.99**	0.84 0.65-1.08	0.97 0.66-1.44	0.96 0.85-1.08	0.95 0.83-1.08	****0.84 0.77-0.92**			
Cardiac 2009	1.13 0.97-1.32	1.86 0.65-5.30		#1.16 0.99-1.35	1.07 0.82-1.39	1.13 0.96-1.34	518	59.3 (-11.8, 130.4)	**-207.3* (-308.8, -105.8)**
Cardiac 2014	**0.46** 0.36-0.60**	0.59 0.08-4.39		****0.33 0.23-0.47**	****0.43 0.26-0.69**	****0.56 0.44-0.71**	128	**-148.0 (-220.4, -75.5)**	
2014:2009	**0.41* 0.30-0.56**	0.32 0.03-3.06		****0.29 0.19-0.42**	***0.40 0.23-0.69**	****0.50 0.36-0.79**			

Emergency presentations

Table 4 presents the IRRs of the emergency presentations for the 2009 and 2014 heatwaves. Total emergency presentations were increased during hw2009, however in hw2014 a significant 3% decrease was observed when compared to non-heatwave periods. This inverse risk was predominantly observed in the younger age groups. Comparison of the hw2009 and hw2014 IRRs indicated that the reduction was significant for emergency presentations in the 75+ age group only. Renal and heat-related presentations were significantly increased within several age groups during hw2009. During the hw2014, renal presentations were very similar to the non-heatwave periods indicated by IRRs near one. Heat-related IRRs were reduced by one-third, but still indicated significant increases over non-heatwave periods.

Comparing 2009 and 2014

When compared, renal and heat-related IRRs were statistically significantly reduced for total presentations and for almost all age groups.

Total emergency presentations were reduced by 440 compared to non-heatwave periods (table 4) in 2014, while in 2009 an excess of 302 cases was estimated. On both occasions the confidence intervals were wide and the results were non-significant. The difference between 2009 and 2014 presentations indicated a non-significant reduction of 742 cases.

There were 125 excess renal presentations estimated during hw2009 and a reduction of 8.7 cases in 2014.The difference between 2009 and 2014 was statistically significant with an estimated 134 (30%) fewer renal cases than expected.

The excess in heat-related presentations during hw2014 was estimated to be 160 cases, approximately half of the excess 304 cases in 2009. The difference between the 2009 and 2014 events showed a significant reduction of 145 (56%) heat-related cases compared to expected cases.

*Table 4 Emergency IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of emergency presentations during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. **P<0.001; * p<0.05; #p<0.1*

	Emergency presentation								
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases	Excess/ Reduction of cases (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	*1.02 (1.01-1.04)	*0.90 (0.81-1.00)	*0.83 (0.71-0.97)	1.05 (0.99-1.12)	1.004 (0.91-1.11)	**1.17 (1.11-1.22)	12928	301.7 (-318.7, 922.2)	-741.5 (-1658.6, 175.6)
total 2014	**0.97 (0.95-0.98)	**0.83 (0.75-0.92)	*0.78 (0.66-0.91)	1.02 (0.96-1.09)	0.97 (0.88-1.07)	0.99 (0.94-1.03)	12998	-439.8 (-1115.1, 235.6)	
2014-2009	0.95 (0.88-1.01)	0.92 (0.89-1.07)	0.94 (0.75-1.18)	0.97 (089-1.07)	0.97 (0.84-1.11)	**0.85 (0.79-0.90)			
Renal 2009	**1.39 (1.23-1.58)	*1.51 (1.02-2.23)	1.25 (0.71-2.21)	**1.32 (1.16-1.50)	1.21 (0.88-1.67)	**1.67 (1.32-2.13)	443	125.2 (84.4, 166.0)	-133.9** (-201.1,-66.7)
Renal 2014	0.98 (0.85-1.13)	0.82 (0.51-1.31)	0.84 (0.45-1.60)	0.97 (0.84-1.12)	0.78 (0.55-1.11)	1.15 (0.88-1.49)	359	-8.7 (-62.1, 44.7)	
Renal 2014;2009	**0.70 (0.58-0.85)	*0.54 (0.29-1.00)	0.67 (0.29-1.59)	*0.74 (0.61-0.89)	#0.64 (0.40-1.04)	*0.69 (0.48-0.98)			
Heat-related total 2009	**12.03 (9.23-15.68)	*3.36 (1.54-7.30)	*3.94 (1.30-11.94)	**12.41 (8.69-17.74)	**9.48 (6.13-14.65)	**15.85 (12.49-20.12)	332	304.4 (297.0, 311.8)	-144.8** (-159.2, -130.4)
Heat-related total 2014	**5.27 (3.81-7.30)	1.23 (0.49-3.08)	*3.91 (1.40-10.94)	**6.10 (4.02-9.25)	**4.41 (2.75-7.06)	**6.12 (4.70-7.97)	197	159.6 (147.3, 172.0)	
Heat-related 2014:2009	**0.44 (0.29-0.67)	0.37 (0.11-1.22)	0.99 (0.22-4.48)	*0.49 (0.28-0.85)	*0.47 (0.25-0.88)	**0.39 (0.27-0.55)			

Mortality

When compared to non-heatwave periods, total mortality increased during hw2009 (11%) and hw2014 (12%) with the increase during hw2014 being statistically significant. Table 5 displays the estimates for excess mortality for the 2009 and 2014 events and indicates that the difference between hw2009 (34.5 cases) and hw2014 (38.2 cases) were approximately 4 extra mortality cases, which was not statistically significant.

Hospital admissions

The results from the analysis of hospital admissions data showed similar trends to emergency presentations, with a reduced impact on renal and heat-related hospital admissions apparent during hw2014 compared to hw2009. These results are included in the online appendix as table 2.

*Table 5 Mortality IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of mortality during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. **P<0.001; * p<0.05; #p<0.1*

	Mortality								
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases	Excess/ Reduction of cases (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	#1.11 1.00-1.24	1.49 0.53-4.18	4.33 0.45-41.66	***1.44** **1.14-1.82**	1.16 0.86-1.56	1.01 0.88-1.16	347	34.5 0.2, 68.9	3.7
total 2014	***1.12** **1.00-1.24**	0.69 0.09-5.13		**#1.25** **0.98-1.61**	0.99 0.72-1.35	1.11 0.98-1.27	364	**38.2** **3.3, 73.1**	-45.3, 52.6
2014:2009	1.01 0.86-1.17	0.46 0.048-4.44		0.87 0.62-1.22	0.85 0.55-1.31	1.10 0.91-1.33			

DISCUSSION

Quantitative evaluation of the effectiveness of public health interventions for heatwaves can be difficult if comparable weather conditions do not occur thereafter. In summer 2014, extreme heat warnings were pronounced twice in short succession in Adelaide and the heat intensity and duration closely resembled the single extreme 2009 event. This conjuncture enabled a quantitative assessment of a HWS (the intervention) which was introduced after the 2009 heatwave.

The evaluation of an intervention is an important task considering that intervention measures can be costly. There are various measures of success including improvement of public awareness, behaviour changes or reduced health outcomes.[23] The latter was the aim of this evaluation. The cornerstones of the intervention are the threshold-based triggers for activation of the system, the Red Cross welfare checks, extensive media coverage and the roll-out of heat plans into the relevant vulnerable communities.[13-14]

Our analysis indicates that the heatwave event in 2014 was associated with fewer adverse health outcomes than observed during hw2009, including ambulance call-outs, emergency presentations and hospital admissions. As the two heatwave events were comparable in their duration and intensity, our findings suggest that the interventions during hw2014 were effective in minimising the population health impact of this event.

It is possible that post hw2009 adaptation has occurred and people have implemented changes in their households such as the installation of air conditioners, extra shading, heat-related structural changes to the built environment and behaviour changes. Notwithstanding, the large reductions in health outcomes are unlikely to have occurred without the parallel development of the HWS. This is supported by the findings from a recent heat-related representative survey in the older population in South Australia following introduction of the HWS, which established that 76.4% of the 499 responders recalled health warnings being issued during extreme heat in SA.[17] The two messages that stood out most as being recalled were “stay hydrated” (78%) and “minimise sun exposure” (53%). Also, when asked about change of behaviour due to heat warnings, 44% of respondents answered positively.

While direct-heat related IRRs were reduced in the hw2014 compared to the hw2009, they still were significantly increased indicating scope for further prevention measures. Not so for renal disease, where no detectable increases in renal presentations were indicated in the hw2014. This is surprising considering the consistency in renal studies reporting increases during heatwaves [24-25] and associations between temperature and the number of renal admissions.[26,27] The messages disseminated during the heat warnings in 2014 focussed on personal reduction of heat exposure and the need for adequate hydration.[28] It is possible that the reductions in renal and heat-related cases may have been due to people changing behaviours as a result of the wide distribution of these messages and the special attention attributed to the at-risk population.

While the results show morbidity reductions in 2014 compared with 2009, the excess mortality remained relatively constant. In 2009, 34.5 excess deaths (11%) were estimated and 38.2 (12%) in 2014. Compared to other cities, and considering population size, Adelaide has a low excess mortality during extreme heat. In 2009, simultaneously to the Adelaide heatwave, Victoria reported 374 excess deaths (62% increase).[29] In Chicago in 1995, 700 excess deaths (74% increase on the day with highest excess deaths) were reported and in the major European heat wave of 2003, more than 15,000 (60%) excess deaths occurred in France alone. [30-32] The lower excess mortality in Adelaide, especially in comparison to Victoria, may be explained by better adaptation to heat due to more extensive and extreme historical heat experience. A comparison of heat-health behaviours in older people in Victoria and SA after the 2009 event indicated that older people in SA had a higher prevalence of air conditioners and a higher recall of heat-related warning messages compared to their Victorian counterparts.[33] Nevertheless, an increase of 12% of mortality is still too high considering that deaths due to high temperatures should, in theory, be avoidable. Information about the underlying contributing factors is important to understand how to further refine prevention measures.

Our findings show that during the 2009 and 2014 episodes, the 15-64 year age group was particularly affected by mortality. Occupational exposures and the attitude of having to get on with life and work despite the heat, may have contributed to the increased mortality in this age group. Preliminary evidence from a case-control study in Adelaide indicates that those who died during the 2009 heatwave were much more likely to have had pre-existing heart disease and be lacking in social support compared to the general community control group.[34] This evidence could be useful for the development of further preventive measures and focussed health warnings.

There are some limitations to this study, particularly related to the separation of the hw2014 by a 9 day non-heatwave break. This may have rendered the intervention hw2014 as not entirely comparable to the 13 day continuing episode in 2009. Nevertheless, during both parts of the 2014 heatwaves, maximum temperatures of above 40°C were experienced over several days indicating risks to human health according to heat-health thresholds investigations in Adelaide [13-14].

The evaluation of the effectiveness of the HWS and interventions in Adelaide is at an early stage and this study has explored the effect of the intervention on health outcomes only. In order to make further progress and achieve further reductions it will be necessary to assess how the services provided are received, whether they penetrate to the people most at need, whether their heightened awareness is transformed into likely beneficial behaviour changes and whether these improvements can be sustained.

CONCLUSION

This comparison of two extreme heat events in metropolitan Adelaide, separated by five years, has provided evidence of improvements in health outcomes post intervention measures, mostly linked to reductions in renal and heat-related morbidity. The renal-related health outcomes in 2014 showed significant reductions compared to what was expected in relation to hw2009 suggesting that awareness of warnings and advice during the heatwave may be a contributing factor. While direct heat-related illness dropped significantly, excess cases were still observed during the hw2014. Knowing that long term prognosis can be poor following heat stress and heat stroke, particularly for older people, more emphasis should be placed on better communication with vulnerable groups to reduce heat exposure. While mortality is relatively low during heatwaves in Adelaide compared to other larger cities worldwide and in Australia, better outcomes could still be achieved. Targeted preventive measures may also have benefits to the wider population considering that everybody is potentially at risk. Evaluation of interventions is an iterative process and should be used continuously alongside fine tuning of the intervention measures using evidence-based research.

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Contributor statement

MN: has contributed to the conception and design of the study, has interpreted the data and has drafted the work and revised it critically for important intellectual content.

GT: has contributed to the design of the study, the acquisition, analysis and interpretation of the data and has revised the work for important intellectual content.

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None declared

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The routine data analysed for this study are held with the Department for Health and Ageing, Adelaide, South Australia.

No additional data is available.

Ethical approval:

No ethical approval was required. The study is based on yearly routine heatwave impact assessment using de-identified and aggregated health data.

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Supplementary file

An Evaluation of Two Exceptional Heat Events: The Effects of a Heat Warning System in Adelaide, South Australia.

Table 1 Daily maximum and minimum temperature during the 2009 and the 2014 heatwaves. Shaded area represent days with extreme heat warning in 2014. No warning was implemented in 2009.

Extreme heat period 2009			Extreme heat period 2014/1			Extreme heat period 2014/2		
Date	Min T	Max T	Date	Min T	Max T	Date	Min T	Max T
26-01-09	16.9	36.6	12-01-14	16.6	35.5	27-01-14	17.6	39.1
27-01-09	21.2	43.2	13-01-14	22.1	42.1	28-01-14	20.3	43
28-01-09	30.7	45.7	14-01-14	25.3	45.1	29-01-14	18.8	31.3
29-01-09	33.9	43.4	15 01-14	27.1	43.7	30-01-14	21.7	36.7
30-01-09	29.4	43.1	16 01-14	29.9	44.2	31-01-14	20.9	37.6
31-01-09	27.5	41.1	17-01-14	28.3	42.7	01-02-14	22.7	43.4
01-02-09	25.9	40.6				02-02-14	28.7	44.7
02-02-09	28.3	38.8						
03-02-09	21.5	36.3						
04-02-09	19.3	33						
05-02-09	19.1	35.6						
06-02-09	21	43.9						
07-02-09	25.8	41.5						
Average T	**26.1**	**41.0**		**24.9**	**42.2**		**21.5**	**39.4**
Min T	**16.9**	**36.3**		**16.6**	**35.5**		**17.6**	**31.3**
Max T	**33.9**	**45.7**		**29.9**	**45.1**		**28.7**	**44.7**

Formulae for calculating the standard errors and the 95% confidence intervals for the estimates of the excess/reductions during the respective heatwaves and the differences in cases between the 2009 and 2014 heat events.

Observed cases = N
Expected cases = (N/IRR)
Excess cases = N - (N/IRR)
Calculating the standard error of the excess relies on the following equations;

Var(aX) = a^2*Var(X)
Var(X+Y) = Var(X) + Var(Y) + 2*Cov(X,Y)   note that Cov(X,Y)=0 for independent events.

Var(X/Y) = X^2 / Y^2 * (Var(X) / X^2 + Var(Y) / Y^2 - 2 Cov(X,Y) / XY) note that Cov(X,Y)=0 for independent events.

Therefore Variance for difference in excess from 2009 to 2014

Step1: Variance of IRR: $((\text{IRR upper CI-IRR lower CI})/(2*1.96))^2$

Step 2: var(excess)=var(N) + var(N/IRR)= N^2 *var((IRR)/IRR^4

Where N=observed cases, and the var(N)=0 since N is a constant

= $(N^2*((\text{IRR upper CI-IRR lower CI})/(2*1.96))^2/IRR^4)$

Step 3: 95%CI for excess: excess-1.96*SE ; excess+1.96*SE

Step 4: p-value for excess (z-test): 2*(1-NORMSDIST(ABS(excess/SE(excess))))

Step 5: SE of difference between excess 2009 and 2014: square root(var(excess2009) + var(excess2014))

because the excess for 2009 is independent of the excess for 2014.

To calculate 95% CI for the difference between excess 2009 and 2014

Step 6 : (excess2014-excess2009)-1.96*SE(from step 5), (excess2014-excess2009)+1.96*SE(from step 5)

Step 7: p-value for difference in excess from 2009 to 2014 (z-test): 2*(1-NORMSDIST(ABS((difference in excess)/SE(from step 5))))

*Table 2 Hospital IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of hospital admissions during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. Empty cells indicate insufficient data to produce reliable estimates. **P<0.001; * p<0.05; #p<0.1*

	Hospital Admissions								
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases	Excess/ Reduction of cases (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	1.08 (0.85-1.34)	1.05 (0.87-1.26)	0.79 (0.59-1.07)	1.08 (0.83-1.39)	1.08 (0.83-1.40)	1.14 (0.91-1.42)	17198	1300.1 (-2572.8, 5173.0)	-1317.9 (-7088.3, 4452.5)
total 2014	1.00 (0.78-1.28)	0.92 (0.76-1.11)	0.99 (0.76-1.29)	1.02 (0.78-1.33)	1.01 (0.77-1.32)	0.97 (0.76-1.23)	16900	-17.8 (-4295.4, 4259.9)	
2014-2009	0.92 (0.65-1.31)	0.88 (0.67-1.14)	1.24 (0.84-1.86)	0.95 (0.65-1.37)	0.94 (0.65-1.36)	0.85 (0.62-1.18)			
Renal 2009	1.24 (0.98-1.56)	1.16 (0.67-2.00)	0.74 (9.26-2.07)	1.09 (0.89-1.49)	**#1.38 (0.94-2.01)**	****1.47 (1.19-1.82)**	413	78.6 (-0.4, 157.7)	**-119.1# (-248.9, 10.7)**
Renal 2014	0.89 (0.68-1.17)	1.17 (0.71-1.91)	0.41 (0.90-1.84)	0.80 (0.56-1.14)	0.98 (0.64-1.50)	0.98 (0.77-1.23)	338	-40.7 (-143.5, 62.5)	
Renal 2014-2009	**#0.72 (0.51-1.03)**	1.01 (0.48-2.10)	0.55 (0.90-3.40)	0.74 (0.46-1.18)	0.71 (0.40-1.26)	***0.66 (0.48-0.91)**			
Heat-related total 2009	****13.64 (9.13-20.36)**	***6.50 (1.19-35.49)**		****11.52 (7.31-18.15)**	***7.06 (3.06-16.30)**	****19.21 (12.74-28.96)**	232	**215.0 (208.0,222.0)**	**-141.1** (-155.7, -126.5)**
Heat-related total 2014	****4.35 (2.51-7.53)**	2.42 (0.54-10.93)	***6.65 (1.22-36.33)**	****3.38 (1.79-6.36)**	***4.11 (1.54-11.03)**	****5.16 (2.97-8.95)**	96	**73.9 (61.1, 86.7)**	
Heat-related 2014-2009	****0.32 (0.16-0.63)**	0.37 (0.039-3.61)		***0.29 (0.13-0.64)**	0.58 (0.16-2.12)	****0.27 (0.13-0.53)**			

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract **Pg 1** **Pg 2**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale Pg 4	2	Explain the scientific background and rationale for the investigation being reported
Objectives Pg 5	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design Pg 5	4	Present key elements of study design early in the paper
Setting Pg 4 and 5	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants Pg 5	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **The study "An evaluation of two exceptional heat events: the effects of a heat warning system in Adelaide, South Australia" is an ecological design**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables Pg 5, 7	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement Pg 5, 7	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias discussion	9	Describe any efforts to address potential sources of bias
Study size Population –based study	10	Explain how the study size was arrived at
Quantitative variables Pg 5, 7	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods Pg 7 and appendix for detailed formulae	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed

Case-control study—If applicable, explain how matching of cases and controls was addressed

Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy

(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants Population-based study	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data Ecological design	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data Pg 9	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results Pg 9-15	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results Pg 16	18	Summarise key results with reference to study objectives
Limitations Pg 16, 18	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation Pg 18	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability Pg 18	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding N/A	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

An evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis

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An evaluation of a heat warning system in Adelaide, South Australia, using case-series analysis

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ABSTRACT

Background Heatwave warning systems aim to assist in reducing health effects during extreme heat. Evaluations of such systems have been limited. This study explored the effect on morbidity and mortality of a heatwave warning program in Adelaide, South Australia, by comparing extreme events in 2009 and 2014, the latter with exposure to the preventive program.

Methods The health outcomes during the two heatwaves were compared using the incidence rate ratios of daily ambulance callouts, emergency presentations and mortality data during the heatwaves compared to non-heatwave periods during the warm seasons. Excess or reduced numbers of cases were calculated and the differences in cases between the two heatwaves were estimated.

Results Incidence rate ratios for total ambulance call-outs and emergency presentations were lower during the 2014 heatwaves compared to the 2009 event. The estimated differences in health- specific outcomes between 2009 and 2014 were statistically significant with -207 (59%) for cardiac-related call outs, -134 (30%) for renal and -145 (56%) for heat-related emergency presentations. Mortality was not reduced in 2014. There were an estimated 34.5 excess deaths in 2009 and 38.2 in 2014.

Conclusion Morbidity outcomes were reduced significantly during the 2014 event. The fact that cardiac, renal and heat-related diagnoses were significantly reduced is likely to be associated with the intervention in 2014, which comprised not only a public warning through media, but also intense preventive measures directed to individual populations at risk. Further analysis of risk factors of mortality during heatwaves should be explored.

Strength and Limitations of this study

- Heatwave warning systems based on defined temperature triggers and adaptive public health measures have been implemented in many cities, but the evaluation of the effectiveness of these systems is limited to mortality.
- This study utilised morbidity and mortality data from two extreme heatwave periods, before and after the introduction of a heatwave warning system in Adelaide, South Australia, to compare the impact.
- There are limitations in conclusively evaluating the effects of a population-based heat health intervention. It could be argued that improvements in health outcomes could be due to adaptation to heat or that it is difficult to compare heatwave events.
- Significant morbidity reductions were observed suggesting that preventive measures contributed to this success. As this was not the case for mortality,

further efforts have to be made to explore the reduction of risk factors for mortality during heatwaves.

- Evaluation of interventions is an iterative process and should be used continuously alongside fine tuning of the intervention measures using evidence –based research.

Contributor statement

MN: has contributed to the conception and design of the study, has interpreted the data and has drafted the work and revised it critically for important intellectual content.

GT: has contributed to the design of the study, the acquisition, analysis and interpretation of the data and has revised the work for important intellectual content.

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All authors: have provided final approval of the version published and are in agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

INTRODUCTION

Health effects during extreme heat should be largely preventable. However, during recent heat events worldwide and in Australia, significant increases in morbidity and mortality have been evident. A systematic analysis of health effects during heatwaves (3 or more days of maximum temperature ≥ 35°C) for Adelaide, the capital of South Australia (SA) (1993-2006) indicated morbidity incidence above what is normally expected during summer periods, but did not show any increases in mortality.[1] This changed when a record breaking 13 day heatwave occurred in summer 2009 during which mortality increased by 37% in the 15-64 age groups together with large increases in renal, ischaemic heart disease and direct heat-related morbidity.[2]

The unparalleled event in summer 2009 evoked the need for a heat warning system (HWS) for metropolitan Adelaide's 1.30 million residents, 76.9% of the total SA population, considering the predictions of an increased frequency of extreme heatwaves under the climate change scenario for SA. A HWS was introduced in November 2009, following the extreme heatwave in January and February 2009. These systems are now in place in many cities of the world.

Several HWSs in the United States were initiated in response to extreme heatwaves.[3-4] Since the 2003 heatwave in Europe, HWSs have been also rolled out for many European cities.[5-6] Only recently, the World Health Organisation (WHO) in conjunction with the World Meteorological Organisation (WMO) published a guidance document on the development of HWSs.[7] The Adelaide HWS addresses most of the pertinent elements presented in the WHO/WMO framework including a definition of the event, an across the government agreed division of roles and responsibilities to reduce possible health effects among those at risk, and a communications strategy to engage with the general population. The process of establishing a HWS in Adelaide has been described in a recent qualitative study outlining the collaborative stakeholder engagement process by the state government.[8]

Another key factor mentioned in the WHO/WMO framework is the need to evaluate the success of the health warnings; whether it has offered health protection verified by a reduction of cases of heat-related illnesses compared to what was expected from previous events, or in terms of public recall of information, and whether the warning changed the behaviour of people at risk.[7] Evaluating heat warning interventions has been the subject of two recent reviews.[9-10] They concur that the limited intervention studies present indicated positive results. Most of the studies were limited to the evaluation of mortality. Evaluations of impacts were hampered by the fact that subsequent heatwaves had different intensities and durations.[10-11]

In summer of 2014, the Adelaide extreme heat warning system was twice activated within a one month period, and when combined these two heatwave periods resembled in duration and intensity the 2009 heat event. This provided a timely opportunity to compare health outcomes during those events as part of an evaluation of the effectiveness of the heat health intervention in Adelaide.

METHODS

The study is of ecological design comparing morbidity and mortality of two extreme heatwaves at the population level.

Health data

Morbidity and mortality data for metropolitan Adelaide for the warm seasons (October-March) from 1993 to 2014 were obtained from The Department for Health and Ageing. For comparison purposes, the specific health outcome categories chosen for analysis were those that were significantly increased during the 2009 heatwave. Ambulance callout data were obtained from SA Ambulance Service.

The following International Classification of Disease (ICD-10) categories of diseases were selected for emergency department presentations (hospital admissions data was also obtained and the results can be seen in the appendix online): renal (ICD-10 N00-N399) and direct heat-related (ICD-10, E86, T67, X30). The pre-defined categories provided by SA Ambulance Service for call-outs were used. Only total mortality data were used as cause-specific data for 2014 were unavailable.

Heat health interventions

Table 1 summarises the elements of Adelaide's short-term interventions during extreme heat warning episodes.

The HWS has an all-government approach with the State Emergency Service (SES) as the 'Hazard Leader'.[12] A HWS is triggered during extreme heat events in conjunction with the Bureau of Meteorology (BOM) when an average daily temperature (ADT) of ≥32ºC is forecast for three or more days (average of daily maximum and minimum = ADT; for example 40°C + 24°C/2=32). This temperature threshold is based on retrospective analysis of health and temperature data.[13-14] Upon reaching the threshold, the government activates heat-related interventions to the specific needs of vulnerable populations. For example, all people who access one or more social services are monitored regarding their wellbeing. The general public is warned, informed and educated through media announcements.

The Australian Red Cross operates an important free service in collaboration with the state government, specifically directed to people at risk. Those who have been registered are contacted on a daily basis during the warning period. Carers, doctors, friends and family members can enrol a person in this system based on a vulnerability assessment tool.[15]

Pre-season work is invested into re-assessing extreme heat plans and intervention measures based on ongoing risk factors research.[16-18]

Lead agencies	Triggers/threshold	Interventions	
SA State Emergency Service (SES) is advised by Bureau of Meteorology (BOM). SES informs other agencies with one lead day.	3 day rolling forecast of daily average (minimum and maximum temperatures divided by two) temperatures (ADT) Threshold for an extreme heat warning is reached when ADT is 32C or above (e.g. 40C daytime and 24C night time)	**Before/start of summer and ongoing:** • General heat health advice before summer. • Heat plan review of all relevant government and non-government agencies. • Meeting of all agencies before the summer	**During the alert:** • Activation of specific and co-ordinated extreme heat plans (Local government, state government and non-government), see examples: • Public alerts and advice through media • Continuous review of emergency, ambulance and other

		season to discuss co-ordination issues. • Collaborative Research agenda	clinical response capabilities in the health sector. • Australian Red Cross provision of free support calls to registered vulnerable people.

Table 1: Extreme heat warning in Adelaide, South Australia: description of the program and interventions.

Temperature data

Temperature data were obtained from a BOM weather station which is representative of the metropolitan area of Adelaide.

The definition (3 or more days of ≥35ºC) for heatwave impact assessments in Adelaide was used to compare the health impacts during the 2014 heatwaves to those in 2009.[1-2] The 2009 heatwave (hw2009) (26 January to 7 February) lasted 13 days with an average maximum temperature of 41°C and an average minimum temperature of 26.1°C. The 2014 heatwave (hw2014) is a composite of two heatwaves with only 9 days in between (12 January to 17 January and 27 January to 2 February 2014). Each of the events (hw2009 and hw2014) included one day below 35°C. The average maximum temperature during the first component of the hw2014 was 42.2°C and the minimum was 24.8; for the second composite period it was 39.4 and 21.5 accordingly. During both hw2014 periods, extreme heat warnings were triggered. Table 1 in the online appendix shows the temperature constellation for the 2009 and 2014 heatwaves in more details highlighting the days during which an extreme heat warning was triggered (based on ADT=32°C forecast by BOM).

Statistics

To compare health impacts, a case series analysis was used.[19] Average daily rates of adverse health outcomes during the defined heatwaves were compared with non-heatwave periods during the respective warm seasons. The rate ratios of incidences of health outcomes during 'case' and 'control' periods were expressed as incidence rate ratios (IRR).

The analysis was conducted within years, therefore implicitly adjusting for long-term trends for the years 1993-2014 which provides more accurate standard errors when data are over dispersed.[20] To calculate the IRR, poisson regression models were fitted using the statistical software package Stata version 13.[21] Each model was tested for fit, and negative binomial regression models were used to allow for over-dispersion if required. To assess the impact of the intervention, the statistical significance of the difference between the 2009 and 2014 IRRs were estimated using the post estimation command 'lincom' in Stata. Furthermore, expected cases were calculated from the total of the observed cases (N) during the respective heatwave period divided by the IRR of the relevant health outcome. Excess (or reduced) cases were obtained by subtracting expected from observed cases [N – (N/IRR)]. The difference between excess cases in 2009 and 2014 provided an indicator of effectiveness of the intervention. Standard errors were manipulated using the formulae provided in Hansen et al to produce a 95% confidence interval (CI) for the estimates of the excess/reduction and the difference in cases between the 2009 and 2014 events (see appendix for formulae).[22]

RESULTS

Table 2 provides summary statistics for daily average health outcomes during the two comparison heatwave and non-heatwave periods in 2009 and 2014. Ambulance call-outs during the hw2009 and hw2014 were higher compared to their respective non-heatwave periods. Unlike in the hw2009 when average daily hospital and emergency presentations were higher than during the respective non-heatwave periods, this was reversed in the hw2014. As in 2009, average mortality was higher during the heatwave compared to the non-heatwave days in 2014.

Table 2 Descriptive statistics for total daily health outcomes for summer 2008/9 and 2013/14 (October to March), for the two defined heatwaves (hw) (13 days) and non-heat wave periods(169 days): minimum, maximum, mean and standard deviation of daily incidences of ambulance call-outs, hospital admissions, emergency presentations and mortality.

Description	Min.	Max.	Mean	SD.
Ambulance call-outs				
hw 2009: 13 days	243	361	291.1	36.1
Non-hw periods in 2009 169 days	187	301	249.5	20.1
hw 2014: 13 days	306	392	342.9	25.4
Non-hw periods 2014 169 days	258	391	326.4	25.0
Hospital admissions				
hw 2009	460	1742	1322.9	506.4
Non-hw periods 2009	271	1798	1231.5	523.4
hw 2014	399	1713	1300.0	528.8
Non-hw periods 2014	334	1972	1311.7	553.9
Emergency department presentations				
hw 2009	905	1065	994.5	54.3
Non-hw periods 2009	802	1122	971.5	59.0
hw 2014	918	1139	999.9	55.7
Non-hw periods 2014	915	1209	1034.3	66.4
Mortality				
hw 2009	15	44	28.6	9.4
Non-hw periods 2009	14	41	26.1	5.6
hw 2014	21	34	28.0	4.1
Non-hw periods 2014	15	38	25.3	4.7

Ambulance call-outs

Table 3 shows the IRRs for ambulance call-outs during heatwaves compared to non-heatwave periods in 2009 and 2014. In 2009, the incidence of total ambulance call-outs increased by 16% over non-heatwaves in the warm season. Compared to hw2009, total call-outs were decreased during hw2014, with the 2014 point estimate indicating a non-significant 5% increase over non-heatwave periods. Reductions compared to hw2009 were also evident across all age groups.

Total and age-related cardiac-related call-outs in 2014 showed a protective effect during the heatwaves compared to the non-heatwave periods. In 2009 the reverse occurred.

Comparing 2014 and 2009

Comparing IRRs indicated significant reductions in all-age total and cardiac-related call-outs occurring in 2014. Age specific differences were manifest in the 75+ age group for total call-outs and for cardiac call-outs in all adult age groups.

There were 220 excess ambulance call-outs estimated during the hw2014 compared to 518 in the hw2009 (table 3). Fifty nine excess cardiac-related call-outs were estimated for the 2009 heatwave; in 2014, a significant reduction of 148 cardiac-related call-outs was assessed. Based on these estimates there were 297 (9%) fewer total call-outs and 207 (59%) fewer cardiac-related call-outs during the hw2014 than the hw2009 outcomes.

Table 3: Ambulance call-outs IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of ambulance call-outs during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. Excess or reduction of ambulance call-outs during the 2009 and the 2014 heatwaves and comparison between 2009 and 2014 (Expected cases = observed cases divided by the IRR; Excess/reduced cases = observed cases-expected cases; comparison between 2009 and 2014= excess/reduced 2014 cases–2009 excess/reduced cases)
*Empty cells indicate insufficient data to produce reliable estimates. **P<0.001; * p<0.05; #p<0.1*

Ambulance Call-outs									
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases IRR (95% CI)	Excess/ Reduction (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	**1.16** (1.09-1.24)**	1.08 (0.90-1.29)	0.86 (0.64-1.15)	***1.14 (1.04-1.24)**	***1.11 (1.01-1.23)**	****1.24 (1.17-1.33)**	3760	**517.5 (308.2, 726.8)**	-297.3# (-644.4, 49.8)
total 2014	1.05 0.99-1.12	0.90 0.75-1.08	0.83 0.64-1.09	#1.09 1.00-1.19	1.06 0.97-1.15	1.04 0.98-1.11	4457	220.2 (-56.7, 497.1)	
2014:2009	**0.91* 0.83-0.99**	0.84 0.65-1.08	0.97 0.66-1.44	0.96 0.85-1.08	0.95 0.83-1.08	****0.84 0.77-0.92**			
Cardiac 2009	1.13 0.97-1.32	1.86 0.65-5.30		#1.16 0.99-1.35	1.07 0.82-1.39	1.13 0.96-1.34	518	59.3 (-11.8, 130.4)	**-207.3* (-308.8, -105.8)**
Cardiac 2014	**0.46** 0.36-0.60**	0.59 0.08-4.39		****0.33 0.23-0.47**	****0.43 0.26-0.69**	****0.56 0.44-0.71**	128	**-148.0 (-220.4, -75.5)**	
2014:2009	**0.41* 0.30-0.56**	0.32 0.03-3.06		****0.29 0.19-0.42**	***0.40 0.23-0.69**	****0.50 0.36-0.79**			

Emergency presentations

Table 4 presents the IRRs of the emergency presentations for the 2009 and 2014 heatwaves. Total emergency presentations were increased during hw2009, however in hw2014 a significant 3% decrease was observed when compared to non-heatwave periods. This inverse risk was predominantly observed in the younger age groups. Comparison of the hw2009 and hw2014 IRRs indicated that the reduction was significant for emergency presentations in the 75+ age group only. Renal and heat-related presentations were significantly increased within several age groups during hw2009. During the hw2014, renal presentations were very similar to the non-heatwave periods indicated by IRRs near one. Heat-related IRRs were reduced by by more than half, but still indicated significant increases over non-heatwave periods.

Comparing 2009 and 2014

When compared, renal and heat-related IRRs were statistically significantly reduced for total presentations and for almost all age groups.

Total emergency presentations were reduced by 440 compared to non-heatwave periods (table 4) in 2014, while in 2009 an excess of 302 cases was estimated. On both occasions the confidence intervals were wide and the results were non-significant. The difference between 2009 and 2014 presentations indicated a non-significant reduction of 742 cases.

There were 125 excess renal presentations estimated during hw2009 and a reduction of 8.7 cases in 2014.The difference between 2009 and 2014 was statistically significant with an estimated 134 (30%) fewer renal cases than expected.

The excess in heat-related presentations during hw2014 was estimated to be 160 cases, approximately half of the excess 304 cases in 2009. The difference between the 2009 and 2014 events showed a significant reduction of 145 (56%) heat-related cases compared to expected cases.

*Table 4 Emergency IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of emergency presentations during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. **P<0.001; * p<0.05; #p<0.1*

	Emergency presentation								
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases	Excess/ Reduction of cases (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	*1.02 (1.01-1.04)	*0.90 (0.81-1.00)	*0.83 (0.71-0.97)	1.05 (0.99-1.12)	1.004 (0.91-1.11)	**1.17 (1.11-1.22)	12928	301.7 (-318.7, 922.2)	-741.5 (-1658.6, 175.6)
total 2014	**0.97 (0.95-0.98)	**0.83 (0.75-0.92)	*0.78 (0.66-0.91)	1.02 (0.96-1.09)	0.97 (0.88-1.07)	0.99 (0.94-1.03)	12998	-439.8 (-1115.1, 235.6)	
2014-2009	0.95 (0.88-1.01)	0.92 (0.89-1.07)	0.94 (0.75-1.18)	0.97 (089-1.07)	0.97 (0.84-1.11)	**0.85 (0.79-0.90)			
Renal 2009	**1.39 (1.23-1.58)	*1.51 (1.02-2.23)	1.25 (0.71-2.21)	**1.32 (1.16-1.50)	1.21 (0.88-1.67)	**1.67 (1.32-2.13)	443	125.2 (84.4, 166.0)	-133.9** (-201.1,-66.7)
Renal 2014	0.98 (0.85-1.13)	0.82 (0.51-1.31)	0.84 (0.45-1.60)	0.97 (0.84-1.12)	0.78 (0.55-1.11)	1.15 (0.88-1.49)	359	-8.7 (-62.1, 44.7)	
Renal 2014;2009	**0.70 (0.58-0.85)	*0.54 (0.29-1.00)	0.67 (0.29-1.59)	*0.74 (0.61-0.89)	#0.64 (0.40-1.04)	*0.69 (0.48-0.98)			
Heat-related total 2009	**12.03 (9.23-15.68)	*3.36 (1.54-7.30)	*3.94 (1.30-11.94)	**12.41 (8.69-17.74)	**9.48 (6.13-14.65)	**15.85 (12.49-20.12)	332	304.4 (297.0, 311.8)	-144.8** (-159.2, -130.4)
Heat-related total 2014	**5.27 (3.81-7.30)	1.23 (0.49-3.08)	*3.91 (1.40-10.94)	**6.10 (4.02-9.25)	**4.41 (2.75-7.06)	**6.12 (4.70-7.97)	197	159.6 (147.3, 172.0)	
Heat-related 2014:2009	**0.44 (0.29-0.67)	0.37 (0.11-1.22)	0.99 (0.22-4.48)	*0.49 (0.28-0.85)	*0.47 (0.25-0.88)	**0.39 (0.27-0.55)			

Mortality

When compared to non-heatwave periods, total mortality increased during hw2009 (11%) and hw2014 (12%) with the increase during hw2014 being statistically significant. Table 5 displays the estimates for excess mortality for the 2009 and 2014 events and indicates that the difference between hw2009 (34.5 cases) and hw2014 (38.2 cases) were approximately 4 extra mortality cases, which was not statistically significant.

Hospital admissions

The results from the analysis of hospital admissions data showed similar trends to emergency presentations, with a reduced impact on renal and heat-related hospital admissions apparent during hw2014 compared to hw2009. These results are included in the online appendix as table 2.

*Table 5 Mortality IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of mortality during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. **P<0.001; * p<0.05; #p<0.1*

Mortality									
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases	Excess/ Reduction of cases (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	#1.11 1.00-1.24	1.49 0.53-4.18	4.33 0.45-41.66	***1.44** **1.14-1.82**	1.16 0.86-1.56	1.01 0.88-1.16	347	34.5 0.2, 68.9	3.7 -45.3, 52.6
total 2014	***1.12** **1.00-1.24**	0.69 0.09-5.13		**#1.25** **0.98-1.61**	0.99 0.72-1.35	1.11 0.98-1.27	364	**38.2** **3.3, 73.1**	
2014:2009	1.01 0.86-1.17	0.46 0.048-4.44		0.87 0.62-1.22	0.85 0.55-1.31	1.10 0.91-1.33			

DISCUSSION

Quantitative evaluation of the effectiveness of public health interventions for heatwaves can be difficult if comparable weather conditions do not occur thereafter. In summer 2014, extreme heat warnings were pronounced twice in short succession in Adelaide and the heat intensity and duration closely resembled the single extreme 2009 event. This conjuncture enabled a quantitative assessment of a HWS (the intervention) which was introduced after the 2009 heatwave.

There was only one other notable heat event in recent years occurring in March 2008, with 15 consecutive days of 35°C and over, but temperatures merely skimmed the 40°C mark. The heatwave was therefore not comparable with the 2009 and 2014 events which all included consecutive days well over 40°C including high overnight temperatures, a heat health threshold pattern that is now recognised as being associated with considerable risks in Adelaide's population.[2, 13-14]

The evaluation of an intervention is an important task considering that intervention measures can be costly. There are various measures of success including improvement of public awareness, behaviour changes or reduced health outcomes.[23] The latter was the aim of this evaluation. The cornerstones of the intervention are the threshold-based triggers for activation of the system, the Red Cross welfare checks, extensive media coverage and the roll-out of heat plans into the relevant vulnerable communities.[13-14]

Our analysis indicates that the heatwave event in 2014 was associated with fewer adverse health outcomes than observed during hw2009, including ambulance call-outs, emergency presentations and hospital admissions. As the two heatwave events were comparable in their duration and intensity, our findings suggest that the interventions during hw2014 were effective in minimising the population health impact of this event.

It is possible that post hw2009 adaptation has occurred and people have implemented changes in their households such as the installation of air conditioners, extra shading, heat-related structural changes to the built environment and behaviour changes. Notwithstanding, the large reductions in health outcomes are unlikely to have occurred without the parallel development of the HWS. This is supported by the findings from a recent heat-related representative survey in the older population in South Australia following introduction of the HWS, which established that 76.4% of the 499 responders recalled health warnings being issued during extreme heat in SA.[17] The two messages that stood out most as being recalled were "stay hydrated" (78%) and "minimise sun exposure" (53%). Also, when asked about change of behaviour due to heat warnings, 44% of respondents answered positively.

While direct-heat related IRRs were reduced in the hw2014 compared to the hw2009, they still were significantly increased indicating scope for further prevention measures. An apparent protective effect of heatwaves on renal emergency presentations in 2014 (and hospital-related; in supplementary file) is counter-intuitive considering our previous renal results and evidence from other studies.[24-27] It may have been due to people being particularly cautious about maintaining hydration in response to heat warnings, but overlooking the importance of fluid intake throughout summer. The messages disseminated during the heat warnings in 2014 focussed on personal reduction of heat exposure and the need for adequate hydration.[28] It is possible that the reductions in renal and heat-related cases may have been due to people changing behaviours as a result of the wide distribution of these messages and the special attention attributed to the at-risk population.

While the results show morbidity reductions in 2014 compared with 2009, the excess mortality remained relatively constant. In 2009, 34.5 excess deaths (11%) were estimated and 38.2 (12%) in 2014. Compared to other cities, and considering population size, Adelaide has a low excess mortality during extreme heat. In 2009, simultaneously to the Adelaide heatwave, Victoria reported 374 excess deaths (62% increase).[29] In Chicago in 1995, 700 excess deaths (74% increase on the day with highest excess deaths) were reported and in the major European heat wave of 2003, more than 15,000 (60%) excess deaths occurred in France alone.[30-32] The lower excess mortality in Adelaide, especially in comparison to Victoria, may be explained by better adaptation to heat due to more extensive and extreme historical heat experience. A comparison of heat-health behaviours in older people in Victoria and SA after the 2009 event indicated that older people in SA had a higher prevalence of air conditioners and a higher recall of heat-related warning messages compared to their Victorian counterparts.[33] Nevertheless, an increase of 12% of mortality is still too high considering that deaths due to high temperatures should, in theory, be avoidable. Information about the underlying contributing factors is important to understand how to further refine prevention measures.

Our findings show that during the 2009 and 2014 episodes, the 15-64 year age group was particularly affected by mortality. Occupational exposures and the attitude of having to get on with life and work despite the heat, may have contributed to the increased mortality in this age group. Preliminary evidence from a case-control study in Adelaide indicates that those who died during the 2009 heatwave were much more likely to have had pre-existing heart disease and be lacking in social support compared to the general community control group.[34]This evidence could be useful for the development of further preventive measures and focussed health warnings.

There are some limitations to this study, particularly related to the separation of the hw2014 by a 9 day non-heatwave break. This may have rendered the intervention hw2014 as not entirely comparable to the 13 day continuing episode in 2009. Nevertheless, during both parts of the 2014 heatwaves, maximum temperatures of above 40°C were experienced over several days indicating risks to human health according to heat-health thresholds investigations in Adelaide. [13-14]It is essential to continue evaluating future extreme heatwaves considering that the 2014 heatwaves are so far the only ones comparable in severity to the pre-intervention 2009 heatwave. The evaluation of the effectiveness of the HWS and interventions in Adelaide are therefore at an early stage and this study has explored the effect of the intervention on health outcomes only. In order to make further progress and achieve further reductions it will be necessary to assess how the services provided are received, whether they penetrate to the people most at need, whether their heightened awareness is transformed into likely beneficial behaviour changes and whether these improvements can be sustained.

Further studies requiring more detailed information about severity and sub-categories of the critical health outcomes studied, co-existing diseases and other risk factors will enhance future evaluations.

CONCLUSION

Monitoring population health outcomes during extreme heat events is essential to inform the ongoing development of public health interventions. This comparison of extreme heat events in metropolitan Adelaide, five years apart, has provided initial evidence of improvements in health outcomes, possibly associated with the introduction of a heat warning system and public health intervention measures. Notwithstanding some differences between the two heatwaves, they represent the most significant recent heat events recorded for this population. Our findings showed there were marked reductions in renal and heat-related morbidity in 2014 compared to what was expected in relation to hw2009 suggesting that awareness of warnings and advice during the heatwave may be a contributing factor. While direct heat-related illness dropped significantly, excess cases were still observed during the hw2014. Knowing that long term prognosis can be poor following heat stress and heat stroke, particularly for older people, more emphasis should be placed on better communication with vulnerable groups to reduce heat exposure. While mortality is relatively low during heatwaves in Adelaide compared to other larger cities worldwide and in Australia, better outcomes could still be achieved. Targeted preventive measures may also have benefits to the wider population considering that everybody is potentially at risk. Evaluation of interventions is an iterative process and should be used continuously alongside fine tuning of the intervention measures using evidence-based research.

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Competing Interests:

None declared

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Data sharing statement:

The routine data analysed for this study are held with the Department for Health and Ageing, Adelaide, South Australia.

No additional data is available.

Ethical approval:

No ethical approval was required. The study is based on yearly routine heatwave impact assessment using de-identified and aggregated health data.

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Supplementary file

An Evaluation of Two Exceptional Heat Events: The Effects of a Heat Warning System in Adelaide, South Australia.

Table 1 Daily maximum and minimum temperature during the 2009 and the 2014 heatwaves. Shaded area represent days with extreme heat warning in 2014. No warning was implemented in 2009.

Extreme heat period 2009			Extreme heat period 2014/1			Extreme heat period 2014/2		
Date	Min T	Max T	Date	Min T	Max T	Date	Min T	Max T
26-01-09	16.9	36.6	12-01-14	16.6	35.5	27-01-14	17.6	39.1
27-01-09	21.2	43.2	13-01-14	22.1	42.1	28-01-14	20.3	43
28-01-09	30.7	45.7	14-01-14	25.3	45.1	29-01-14	18.8	31.3
29-01-09	33.9	43.4	15 01-14	27.1	43.7	30-01-14	21.7	36.7
30-01-09	29.4	43.1	16 01-14	29.9	44.2	31-01-14	20.9	37.6
31-01-09	27.5	41.1	17-01-14	28.3	42.7	01-02-14	22.7	43.4
01-02-09	25.9	40.6				02-02-14	28.7	44.7
02-02-09	28.3	38.8						
03-02-09	21.5	36.3						
04-02-09	19.3	33						
05-02-09	19.1	35.6						
06-02-09	21	43.9						
07-02-09	25.8	41.5						
Average T	**26.1**	**41.0**		**24.9**	**42.2**		**21.5**	**39.4**
Min T	**16.9**	**36.3**		**16.6**	**35.5**		**17.6**	**31.3**
Max T	**33.9**	**45.7**		**29.9**	**45.1**		**28.7**	**44.7**

Formulae for calculating the standard errors and the 95% confidence intervals for the estimates of the excess/reductions during the respective heatwaves and the differences in cases between the 2009 and 2014 heat events.

Observed cases = N
Expected cases = (N/IRR)
Excess cases = N - (N/IRR)
Calculating the standard error of the excess relies on the following equations;

Var(aX) = a^2*Var(X)
Var(X+Y) = Var(X) + Var(Y) + 2*Cov(X,Y) note that Cov(X,Y)=0 for independent events.

Var(X/Y) = X^2 / Y^2 * (Var(X) / X^2 + Var(Y) / Y^2 - 2 Cov(X,Y) / XY) note that Cov(X,Y)=0 for independent events.

Therefore Variance for difference in excess from 2009 to 2014

Step1: Variance of IRR: $((\text{IRR upper CI-IRR lower CI})/(2*1.96))^2$

Step 2: var(excess)=var(N) + var(N/IRR)= N^2 *var((IRR)/IRR^4

Where N=observed cases, and the var(N)=0 since N is a constant

= $(N^2*((\text{IRR upper CI-IRR lower CI})/(2*1.96))^2/IRR^4)$

Step 3: 95%CI for excess: excess-1.96*SE ; excess+1.96*SE

Step 4: p-value for excess (z-test): 2*(1-NORMSDIST(ABS(excess/SE(excess))))

Step 5: SE of difference between excess 2009 and 2014: square root(var(excess2009) + var(excess2014))

because the excess for 2009 is independent of the excess for 2014.

To calculate 95% CI for the difference between excess 2009 and 2014

Step 6 : (excess2014-excess2009)-1.96*SE(from step 5), (excess2014-excess2009)+1.96*SE(from step 5)

Step 7: p-value for difference in excess from 2009 to 2014 (z-test): 2*(1-NORMSDIST(ABS((difference in excess)/SE(from step 5))))

*Table 2 Hospital IRRs and 95% confidence intervals (95%CI): IRRs are based on the daily incidence of hospital admissions during 2009 and 2014 heatwaves compared to the incidence during non-heatwave periods in metropolitan Adelaide in summer (October-March). The IRRs of 2014 and 2009 were compared to estimate the statistical significance of differences between the two heatwave episodes. Empty cells indicate insufficient data to produce reliable estimates. **P<0.001; * p<0.05; #p<0.1*

Hospital Admissions									
	All ages IRR (95% CI)	0-4 IRR (95% CI)	5-14 IRR (95% CI)	15-64 IRR (95% CI)	65-74 IRR (95% CI)	75+ IRR (95% CI)	Observed cases	Excess/ Reduction of cases (95% CI)	Difference between 2009 and 2014 (95% CI)
total 2009	1.08 (0.85-1.34)	1.05 (0.87-1.26)	0.79 (0.59-1.07)	1.08 (0.83-1.39)	1.08 (0.83-1.40)	1.14 (0.91-1.42)	17198	1300.1 (-2572.8, 5173.0)	-1317.9 (-7088.3, 4452.5)
total 2014	1.00 (0.78-1.28)	0.92 (0.76-1.11)	0.99 (0.76-1.29)	1.02 (0.78-1.33)	1.01 (0.77-1.32)	0.97 (0.76-1.23)	16900	-17.8 (-4295.4, 4259.9)	
2014-2009	0.92 (0.65-1.31)	0.88 (0.67-1.14)	1.24 (0.84-1.86)	0.95 (0.65-1.37)	0.94 (0.65-1.36)	0.85 (0.62-1.18)			
Renal 2009	1.24 (0.98-1.56)	1.16 (0.67-2.00)	0.74 (9.26-2.07)	1.09 (0.89-1.49)	**#1.38 (0.94-2.01)**	**1.47 (1.19-1.82)	413	78.6 (-0.4, 157.7)	**-119.1# (-248.9, 10.7)**
Renal 2014	0.89 (0.68-1.17)	1.17 (0.71-1.91)	0.41 (0.90-1.84)	0.80 (0.56-1.14)	0.98 (0.64-1.50)	0.98 (0.77-1.23)	338	-40.7 (-143.5, 62.5)	
Renal 2014-2009	**#0.72 (0.51-1.03)**	1.01 (0.48-2.10)	0.55 (0.90-3.40)	0.74 (0.46-1.18)	0.71 (0.40-1.26)	*0.66 (0.48-0.91)			
Heat-related total 2009	**13.64 (9.13-20.36)	*6.50 (1.19-35.49)		**11.52 (7.31-18.15)	*7.06 (3.06-16.30)	**19.21 (12.74-28.96)	232	**215.0 (208.0,222.0)**	-141.1**

Heat-related total 2014	**4.35 (2.51-7.53)	2.42 (0.54-10.93)	*6.65 (1.22-36.33)	**3.38 (1.79-6.36)	*4.11 (1.54-11.03)	**5.16 (2.97-8.95)	96	73.9 (61.1, 86.7)	(-155.7, -126.5)
Heat-related 2014-2009	**0.32 (0.16-0.63)	0.37 (0.039-3.61)		*0.29 (0.13-0.64)	0.58 (0.16-2.12)	**0.27 (0.13-0.53)			

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract **Pg 1** **Pg 2**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale Pg 4	2	Explain the scientific background and rationale for the investigation being reported
Objectives Pg 5	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design Pg 5	4	Present key elements of study design early in the paper
Setting Pg 4 and 5	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants Pg 5	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants **The study "An evaluation of two exceptional heat events: the effects of a heat warning system in Adelaide, South Australia" is an ecological design**
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables Pg 5, 7	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement Pg 5, 7	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias discussion	9	Describe any efforts to address potential sources of bias
Study size Population –based study	10	Explain how the study size was arrived at
Quantitative variables Pg 5, 7	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods Pg 7 and appendix for detailed formulae	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed

Case-control study—If applicable, explain how matching of cases and controls was addressed

Cross-sectional study—If applicable, describe analytical methods taking account of sampling strategy

(*e*) Describe any sensitivity analyses

Continued on next page

Results		
Participants Population-based study	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data Ecological design	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data Pg 9	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results Pg 9-15	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion		
Key results Pg 16	18	Summarise key results with reference to study objectives
Limitations Pg 16, 18	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation Pg 18	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability Pg 18	21	Discuss the generalisability (external validity) of the study results
Other information		
Funding N/A	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.