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REVIEW

Evaluating the effectiveness of heat warning systems: systematic review of epidemiological evidence

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Abstract

Objectives To review the existing research on the effectiveness of heat warning systems (HWSs) in saving lives and reducing harm.

Methods A systematic search of major databases was conducted, using “heat, heatwave, high temperature, hot temperature, OR hot climate” AND “warning system”.

Results Fifteen articles were retrieved. Six studies asserted that fewer people died of excessive heat after HWS implementation. HWS was associated with reduction in ambulance use. One study estimated the benefits of HWS to be $468 million for saving 117 lives compared to $210,000 costs of running the system. Eight studies showed that mere availability of HWS did not lead to behavioral changes. Perceived threat of heat dangers to self/others was the main factor related to heeding warnings and taking proper actions. However, costs and barriers associated with taking protective actions, such as costs of running air conditioners, were of significant concern particularly to the poor.

Conclusions Research in this area is limited. Prospective designs applying health behavior theories should establish whether HWS can produce the health benefits they are purported to achieve by identifying the target vulnerable groups.

Keywords Heat warning system · Effectiveness · Mortality · Morbidity · Health beliefs · Health service utilization

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Introduction

Despite variations in defining heatwaves in different climates, the impacts of heatwaves on human life and health are widely documented (Harlan and Ruddell 2011; García-Herrera et al. 2010; Martiello and Giacchi 2010; Sheridan et al. 2009; Huang et al. 2012; Williams et al. 2011; Tong et al. 2010a; Kjellstrom et al. 2010). The 1994 summer heatwave killed 3,000 in South Korea (Kyselý and Kim 2009). In 1995, more than 1,000 people lost their lives as a result of heatwaves in the central USA (Palecki et al. 2001). The 2003 heatwave resulted in over 71,000 excess deaths in Europe, with 76 % of the deaths occurring in three countries of Luxemburg, France and Spain (Robine et al. 2008; Go’mez-Acebo et al. 2012). The 2009 heatwave in Victoria, Australia caused an estimated 374 excess deaths (ABS 2010). Recently, the 2010 heatwave in Russia left an estimated 55,000 deaths (Guha-Sapir et al. 2011).

Heatwaves not only kill, but also more widely adversely affect the health of many others, particularly those susceptible to high temperatures such as people with pre-existing chronic conditions, exposed to prolonged periods of extreme heat, elderly and children, and people living in poverty and isolation (Wang et al. 2012; Bassil et al. 2009; Bobvos et al. 2006; Kovats and Ebi 2006; Mastrangelo et al. 2006; Martinez et al. 2011; Martiello and Giacchi 2010; Green et al. 2010).

To minimize harm to those most vulnerable and at risk, calls have been made to introduce action plans. These plans, which are customized to suit local meteorological and demographic conditions, may include early alerts and advisories combined with emergency public health measures to mitigate the heat dangers. Together these are called "heat warning systems" (HWSs) or "heat health warning systems" (HHWS) (Ebi et al. 2004; Lowe et al. 2011; Matthies et al. 2008; Smoyer-Tomic and Rainham 2001; Bernard and McGeehin 2004; O'Neill et al. 2010). Since people in different climates experience the impacts of heatwaves differently due to their level of acclimatization and preparedness, different localities have tested and adopted different definitions and measurements of a heatwave that trigger an HWS according to their specific conditions (Nicholls et al. 2008; Palecki et al. 2001; Ebi et al. 2004). Such factors may include combinations of minimum and maximum temperatures, duration of a heat period, moisture level and air pollutants (Tong et al. 2010b). The HWS allows managers to implement mitigating interventions and response measures that minimize risk, such as promoting heat protection information through the media, setting up "buddy" registers to check on the vulnerable groups, opening cooling shelters, distributing hydration packs, and providing government subsidies for electricity (Ebi 2007; Hajat et al. 2010; Lowe et al. 2011; Martinez et al. 2011; Matthies et al. 2008; Smoyer-Tomic and Rainham 2001; Tan et al. 2004; Sheridan and Kalkstein 2004).

Despite all these efforts, hot weather continues to take its toll on human health. Whether this toll may have been higher, without such actions in place, is unclear. Therefore, it is fundamentally important to evaluate the effectiveness of HWSs in terms of reducing heat-related mortality and morbidity, analyze their cost-effectiveness, and identify factors that may improve or hinder their effectiveness in protecting the vulnerable populations, such as communication barriers, socio-demographic and perceptual factors, and societal determinants (e.g., community preparedness and engagement) (Hansen et al. 2011; Ibrahim et al. 2012; Iersel and Bi 2009; Kalkstein and Sheridan 2007; Vaneckova et al. 2010; Yu et al. 2010; Semenza et al. 2008a).

This study identified existing evidence and knowledge gaps through focusing on the following questions:

1. How effective are HWSs in terms of reducing heat-related health impacts? If effective, then do their benefits outweigh the costs?
2. What are the factors that may influence the effectiveness of HWS in alerting the public and instigating appropriate responses?

Methods

Search strategy

A systematic literature search was conducted using PubMed, ScienceDirect, Web of Science, Scopus, ProQuest in April and May 2012 and a follow-up search in Cochrane Library in January 2013 to identify relevant material. To broaden the search approach, the following terms were used to find the relevant literature: "heat, heatwave, high temperature, hot temperature, OR hot climate" AND "warning system". No time or language restrictions were applied. The reference lists of the retrieved articles were checked to identify potentially relevant references that may not have been found using the above-mentioned sources and approach. Websites of relevant organizations and authorities were also searched with a focus on US, Europe and Australia for gray literature such as departmental reports and briefs.

Search results were stored in an EndNote library. Duplicates were checked and removed. The titles and abstracts were then screened for relevance to the review questions according to the inclusion and exclusion criteria discussed below. Authors of seemingly relevant conference abstracts and one non-English paper were contacted to find out if a full version of the abstract or an English translation was available. Full texts of all the remaining articles were obtained and examined for the review.

Inclusion and exclusion criteria

In addressing the first question, studies were selected if they included in their analysis the implementation of HWS as an independent factor or intervention in changing heat-related mortality or morbidity. Studies which speculated on the role of HWS only as part of the discussion or conclusion were excluded. Regarding the second question, research-based studies of individuals' knowledge, attitudes and behaviors in relation to heat, its health effects, protective measures, and HWS were considered eligible. Theoretical papers and studies without a focus on heat and effectiveness of HWS were excluded.

A considerable number of the retrieved papers described HWS and their specifications in various parts of the world or compared different meteorological measures in terms of their robustness in forecasting dangerously hot days. Such literature was not within the scope of this review and, therefore, excluded. Where more than one article had used the same data for analysis, only the one with more details and relevance to the review questions was included. Articles without full text, in a language other than English, or without a clear indication of sufficient details about methods and analytical techniques were also excluded.

Quality assessment

Due to the limited number of relevant studies and different methods and designs used by each study, it was impossible to enforce strict quality assessment criteria. This was further exacerbated by the difficulty in establishing a causal relationship between implementation of HWS and reduction in adverse health effects and the role of intermediary factors, which may confound the success of such interventions. Consequently, only full text peer-reviewed papers were selected for inclusion. Conference abstracts, review and editorial articles were excluded. All papers were reviewed, and relevant information was extracted on a spreadsheet.

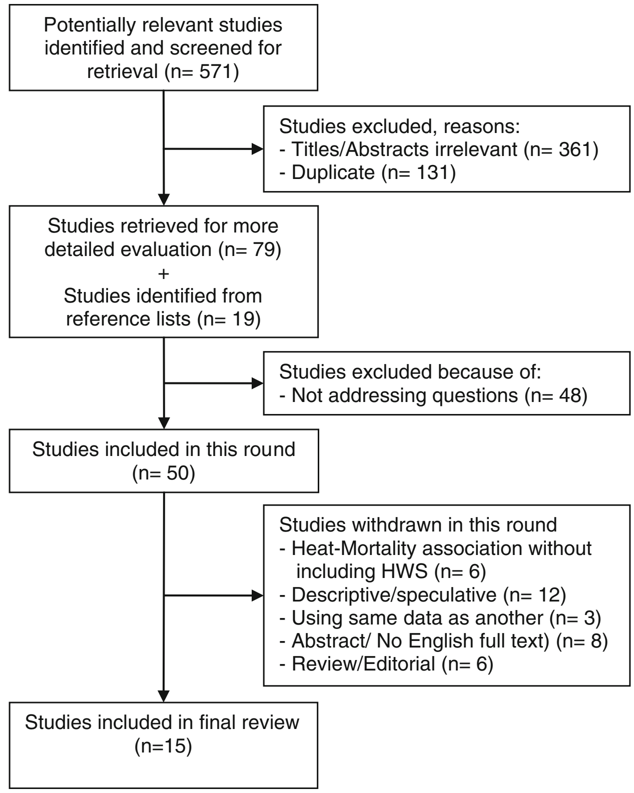

Fig. 1 Flow chart for literature search process

Results

Of the 571 potentially relevant papers, 15 studies fulfilled the inclusion criteria and were included in this review. Seven articles addressed the first research question and eight addressed the second. Figure 1 illustrates the search process and outcomes.

Effectiveness of HWS

Table 1 summarizes the papers addressing the first question on the effectiveness of HWS in reducing mortality and morbidity.

Effectiveness of HWS in reducing heat-related mortality

Six studies asserted that substantially fewer people died of excessive heat after the implementation of HWSs than was expected had such systems not been put in place (Palecki et al. 2001; Weisskopf et al. 2002; Chau et al. 2009; Ebi et al. 2004; Tan et al. 2007; Fouillet et al. 2008). One study was inconclusive (Morabito et al. 2012) (see Table 1 for details). While studies varied in terms of design and variables included in their analyses, they all compared the number [or odds ratios in one case (Morabito et al. 2012)] of deaths in a hot period where no HWS was implemented with a similarly hot period with a HWS implemented. They then attributed the reduction to the implementation of HWS and related mitigating interventions. For instance, the study by Fouillet and colleagues (2008) calculated that if the National Heat Wave Plan had not been implemented, compared with the 2003 heatwave the 2006 summer heat would have caused 4,388 more deaths in France than actually happened.

Due to the nature of their designs, none of the studies was able to establish a causal relationship between the implementation of HWS and reduced mortality. Furthermore, as all studies acknowledged, other factors such as overall improvements in health care, better living conditions including use of air conditioners, heightened heat awareness, use of heat insulating building materials may also have contributed to the reduction in expected mortality.

Effectiveness of HWS in reducing heat-related morbidity

No studies were located that measured the potential impacts or benefits of HWS on reducing morbidity. One study reported that in 1999 the dispatch of emergency medical services (as a proxy indicator for morbidity) in Milwaukee, Wisconsin reduced by 49–73 % on heatwave days with an alert system compared to 1995 without HWS

Table 1 Overview of studies addressing the effectiveness of heat warning systems in reducing health impacts

Study	Location	Design and analysis	Heatwave definition	Independent variable/s	Outcome variable/s	Main findings	Assessment
Chau et al. (2009)	Hong Kong	Comparing excess deaths on days with and without warning (1997–2005) Multiple linear regression	MaxTemp (≥30.4 °C)	Age (≥65); gender HWS implementation (called VHWW)	Excess deaths from IHD or Stroke	Reduction of 727 (IHD) and 574 (Stroke) deaths had HWS been implemented between 1997 and 2005 IHD mortality was very high at MaxTemp ≥34.5 °C regardless of HWS	*Strengths* Compares alert days with non-alert days, even when same temperature Description of HWS measures Specific vulnerable groups (aged, chronic disease), assists with developing and implementing targeted programs *Weaknesses* Not clear how effective other factors, e.g., general improvements and lifestyle changes between 1997 and 2005, were in reducing mortality Unclear if specific components of HWS were more/less effective
Ebi et al. (2004)	Philadelphia- USA	Comparing expected vs. observed death 1995–1998 Cost-benefit analysis Multiple linear regression	Oppressive air masses (maritime tropical and dry tropical) based on HWS (called PWWS)	Daily weather variables Heat duration Time of season Heatwave classification HWS implementation	Excess mortality for ≥65 age group	Average 2.6 lives saved/day of PWWS =Total 117 lives over 3 years (1995–98). According to EPA, each life is worth $4 million =$468 million lives saved compared to $210,000 costs of running HWS	*Strengths* Detailed description of HWS Cost-benefit analysis Inclusion of HWS activation as a variable Comparing effectiveness on similarly hot days with and without HWS *Weaknesses* Fairly old data One city Unclear if specific components of HWS were more/less effective

Table 1 continued

Study	Location	Design and analysis	Heatwave definition	Independent variable/s	Outcome variable/s	Main findings	Assessment
Fouillet al. (2008)	France	Before and after analysis (2003 vs. 2006) Poisson regression	CT_{max} ≥27 °C	HWS implementation	Difference between observed and expected excess mortality	6452 excess deaths were expected but 2065 deaths occurred; 4,387 fewer deaths after HWS	*Strengths* Comparing impacts of 2 heatwaves close to each other, one with and one without HWS Compares alert days with non-alert Detailed description of HWS measures Nation-wide analysis *Weaknesses* Unclear if specific components of HWS were more/less effective HWS period very close to non-HWS period, therefore reduced effects of heat may also be associated with fresh memories of recent heatwave and people's preparedness, not HWS
Morabito et al. (2012)	Florentine—Italy	Before and after analysis (1999–02 vs. 2004–07) Case-crossover stratified by age; OR (95 % CI)	ATave (≥25.5 °C) AT_{max} (≥33.3 °C) AT_{min} (≥18.5 °C)	HWS implementation (called HHWS)	Odds of increasing mortality among age groups 65–74 and ≥75	Odds of mortality reduced only for ≥75 age group from 1.23 to 1.12 when AT_{max} considered Effectiveness of HWS is inconclusive	*Strengths* Compares mortality effects of various temperature levels with and without HWS Studies a vulnerable (aged) population *Weaknesses* Does not describe what HWS plan consists of Does not report data on HWS vs. non-HWS days One city

Table 1 continued

Study	Location	Design and analysis	Heatwave definition	Independent variable/s	Outcome variable/s	Main findings	Assessment
Palecki et al. (2001)	Midwestern USA-focus on Chicago and St. Louise	Comparing 1995 and 1999 Temporal association of meteorological conditions and mortality Descriptive analysis	Average max and min temp = +3 °C above normal	HWS implementation	Potential no. of lives saved	1999 heatwave was as extreme as 1995 but much fewer deaths occurred In Chicago, excess deaths decreased from 700 in 1995 to 114 in 1999 In St. Louise, excess deaths increased from 27 in 1995 to 36 in 1999-explainable by high preparedness level in both periods but more intensive heatwave in 1999	*Strengths* Detailed description and historical account of 1995 and 1999 heatwaves, their impacts, and HWS plan Logical comparative analysis, considering a multitude of factors during heatwaves affecting health *Weaknesses* Fairly old data Lack of statistical analysis, minimizing the ability to quantify and control for factors such as age and gender Unclear if specific components of HWS were more/less effective
Tan et al. (2007)	Shanghai—China	Comparative analysis—1998 and 2003 Descriptive statistics	Temp ≥35 °C lasting ≥3 days (HWS activated)	Age (≥65) AC per capita Living space per capita HWS implementation	Average no. of deaths in all days, heat days and non-heat days	More hot days in 2003 vs. 1998 but fewer deaths in 2003 (358 vs. 253)	*Strengths* Comparing HWS vs. non-HWS days *Weaknesses* One city Unclear what Shanghai's HWS consists of Drastic changes and improvements reported in living conditions between the two periods may account for reduced mortality not HWS

Table 1 continued

Study	Location	Design and analysis	Heatwave definition	Independent variable/s	Outcome variable/s	Main findings	Assessment
Weisskopf et al. (2002)	Milwaukee, Wisconsin—USA	Comparative analysis- 1995 and 1999 Poisson regression and relative risks Observed-to-expected ratios for age-adjusted heat-related deaths	3-h average heat index above 40.6 °C (daytime) and 26.7 °C (night) according to NWS	Heat levels of 1995 and 1999 heatwaves Socio-demographic conditions (age, gender, ethnicity, neighborhood status) HWS implementation	Heat-related deaths; EMS use	Heat levels and characteristics very similar for both periods Excess deaths reduced from 91 in 1995 to 11 in 1999 (80 fewer deaths) EMS dispatch in 1999 decreased to between 27 and 51 % of 1995 level on heatwave days	*Strengths* Analysing EMS use (proxy for morbidity) not just mortality Comparing HWS vs. non-HWS days *Weaknesses* Fairly old data; One city Details of HWS not reported Unclear if specific components of HWS were more/less effective

AC Air-conditioners, *AT* apparent temperature, *CI* confidence intervals, *EMS* emergency medical services, *EPA* environmental protection agency, *HHWS* heat health warning system, *HWS* heat warning system, *IHD* ischemic heart disease, *NWS* national weather service in USA, *OR* odds ratios, *PWWS* Philadelphia hot weather warning system, *VHWW* very hot weather warning system

(Weisskopf et al. 2002). More recent studies have reported an increase in the number of emergency hospital admission (Wang et al. 2012; Josseran et al. 2010; Khalaj et al. 2010) or calls to ambulance (Bassil et al. 2009; Bobvos et al. 2006) during heatwaves. Notably, there are contrasting patterns between hospital admissions and mortalities during heatwaves. While mortalities are more likely to be related to cardiovascular and diabetic causes, non-fatal hospital admissions tend to be higher for dehydration, heat stroke, acute renal failure, and respiratory disease (Wang et al. 2012; Mastrangelo et al. 2006). Further rigorous research is required to evaluate the effectiveness of HWS in reducing morbidity.

Cost-effectiveness of HWS

One study not only measured the number of lives that can be potentially saved by HWS, but also estimated the beneficial value of implementing these systems vis-à-vis their costs. Ebi and colleagues (2004) studied the cost-benefits of implementing the Philadelphia hot weather-health watch warning system in 1995. They showed that for similarly hot days with or without a warning issued during the 1995–1998 period, the excess mortality (calculated as the difference between observed number of deaths and the underlying mortality trend estimated from years prior to 1995) reduced by an average of 2.6 lives per day when a warning was issued. This amounted to a total of 117 lives over the 3-year period for the age group 65 and over. Using an adjusted figure of $4 million based on the Environment Protection Agency's value of a statistical life for people of this age group, they then estimated that in total the saved lives would value $468 million, while the costs of running the HWS were only $210,000 over the same period.

Human response and effectiveness of HWS

Warnings alone if not accompanied by proper measures to mitigate adverse impacts are likely to be less effective. Therefore, many countries have developed or adopted heat health watch programs and measures that are introduced when a heatwave warning is issued according to relevant criteria for each region (Sheridan and Kalkstein 2004; Tan et al. 2004; Wagner et al. 2006; NCCARF 2010; Nicholls et al. 2008). Such programs are intended to increase awareness of risk associated with heat, provide temporary measures to safeguard the populations' health, particularly those of the most vulnerable populations such as the elderly and children. These measures include opening of cooling shelters, use of a "buddy" system, and distributing hydration packs. Mass media messages are broadcast to warn the public of the heat impacts, ways to protect themselves and others, and availability of facilities (Palecki et al. 2001; Martinez et al. 2011; Sheridan and Kalkstein 2004; Lowe et al. 2011). However, evidence is needed to show whether such programs reach and are heeded by the target audience, and if not, what may be the reason. Very few papers were found that addressed this matter. Furthermore, even if used, the effectiveness of each intervention and the evidence behind it, albeit intuitively acceptable, remain unproven. This should be the subject of further scrutiny.

Table 2 presents a summary of articles, which address the second question about the factors that can determine the effectiveness of HWS in reaching the public, particularly at-risk populations, and prompting their response.

Awareness, perception and action

Few studies available maintained that most participants were aware of the heat warnings or high temperature forecasts (Alberini et al. 2011; Kalkstein and Sheridan 2007; Sheridan 2007; Semenza et al. 2008b). However, such awareness did not necessarily lead to taking protective actions. Health behavior and promotion theories suggest that people who see themselves at an elevated risk or susceptible to negative impacts of health-threatening conditions are more likely to take actions to preserve their health (Weinstein 1988; Weinstein et al. 1998). The reviewed studies here confirmed that while the majority of the respondents were aware of the risk, the ones who saw themselves personally vulnerable were more likely to take actions such as using air conditioners, hydrating, staying indoors or in shade, dress properly, avoid extenuating activities, and checking on the elderly or disabled people (Alberini et al. 2011; Kalkstein and Sheridan 2007; Sheridan 2007; Abrahamson et al. 2008; Ibrahim et al. 2012; Richard et al. 2011; Wolf et al. 2010; Semenza et al. 2008b).

On the other hand, those who did not consider themselves susceptible were less likely to act to protect themselves although they would help others if they considered them as affected (Alberini et al. 2011; Kalkstein and Sheridan 2007; Sheridan 2007). Despite the literature putting the elderly at the forefront of the groups susceptible to heat-related health impacts, the qualitative study by Wolf et al. (2010) with 15 persons aged 75 and above found that the participants did not consider themselves old, or vulnerable to or threatened by heat. Interestingly, these participants considered other people of the same age group as vulnerable but not themselves. The authors suggested that adaptation policies needed to address such perceptions as well as introducing initiatives to improve building structures and communication strategies. However, since the sample was very small and in one area, the findings need to be further examined for their generalizability and applicability in other areas and groups.

One study by Ibrahim and colleagues (2012) gauged the knowledge, awareness and practices of the health care providers as related to minimizing heat-related consequences among the elderly. This survey found that overall awareness of protective factors against heat exposure was high, but fewer people knew about thermoregulation. Very few had correct information about hot temperature threshold, sweating and use of fans. The level of awareness varied among the respondents with health care professionals more likely to be knowledgeable than the local government care providers and volunteers.

Summer preparedness

Two studies reported that some people did not change their behavior as a result of heat warnings (Sheridan 2007; Kalkstein and Sheridan 2007). This may at least partly be explained by the fact that many people naturally change their behavior in different temperatures, such as light dressing or drinking more water during summer or wearing warmer clothes in winter. Therefore, they may be generally prepared for summer heat. As a result, they may not see themselves as taking a particular action because of heat warnings and advisories but because of feeling hot in summer and using “common sense” to protect themselves and others. Furthermore, other heat-related health promotion messages, such as the Slip-Slop-Slap sun protection campaign in Australia (Cancer Council Australia 2012), may help alter people’s behavior which may also protect them against heatwave impacts. However, it is to be noted that relying on “common sense” and personal feeling of heat may have detrimental effects particularly on the vulnerable and isolated people whose conditions may deteriorate rapidly as a result of extreme heat and not being able to seek timely assistance.

Costs and barriers

Receiving information about how to protect themselves and perceiving the situation as threatening does not always result in effective action. This is more likely to occur if the costs and barriers to that action are perceived as reasonable or the benefits of taking the action outweigh the costs (Champion and Sugg Skinner 2008). Sheridan (2007) reported that between 30 and 47 % of their survey participants in various cities of Canada expressed that the costs of running an air-conditioner was a factor they had to consider during a heatwave. They did not report more socio-demographic details of these respondents nor did they report if they used their systems during the heatwave. However, the authors acknowledged that because they used

Table 2 Overview of studies about the effectiveness of heat warning systems in alerting human response

Study	Location	Design	Independent variable/s	Outcome variable/s	Main findings	Assessment
Abrahamson et al. (2008)	London and Norwich—UK	Qualitative July–Sept 2007 Elderly (72–94) 73 semi-structured interviews Respondents identified and contacted by GPs Analysis: framework approach	Perceived vulnerability to heat Protective actions by participants and carers Experience of heatwave plan Expected effective interventions for impending heatwaves	–	Participants did not perceive themselves "vulnerable" (i.e., old or at risk), while all were aged and most had some relevant chronic illness Some concerns and confusions about keeping homes cool and coping during prolonged heat periods Many considered measures to protect the elderly living in the community as undesirable and impossible to implement, e.g., receiving home visit from GPs Re Heatwave Plan, many considered info leaflets less useful; suggested use of other media and shows, increasing local engagements such as checking on the people and offering assistance	*Strengths* Qualitative study gaining in-depth information Comparing 2 different cities Good sample size for study design *Weaknesses* Selection bias due to filtering by GPs Recall bias
Alberini et al. (2011)	Fredericton, Winnipeg, Windsor, Regina, Sarnia-Canada	Online survey; 2–18 Sep 2010 (summer) Sample: 1141 aged ≥25 l Before implementing HWS (called HARS) Descriptive analysis	Experience with excessive heat Experiencing heat-related illness Protective impact of AC Earnings and coping with excessive heat Awareness of public health programs and vulnerable populations	Public awareness and opinions impact effectiveness of HWS to be initiated in Canada	High recollections of recent heatwaves awareness through media and weather forecasts Generally good awareness of heatwaves and their potentially severe health impacts (73.3 % agreement) About 80 % would do something for themselves 95 % for children and elderly to protect from heat (e.g., AC, staying in shade, hydrating, going to a cool place) Low awareness of cooling centers in their areas of residence, and varied by location (from 3.5 % in Regina to 34.2 % in Sarnia) About 21 % experienced minor heat-related illness, associated with living outside Regina, being female, under 30yo, and having chronic illness. AC not related	*Strengths* Large sample in various locations Inclusion of younger age groups *Weaknesses* Lack of a theoretical framework Survey tool not tested/piloted Online survey subject to selection bias Sampling and representativeness not described Retrospective information subject to recall bias
Ibrahim et al. (2012)	Victoria—Australia	Cross-sectional Online survey in Jun-Sep 2008 Personnel of six community-based health profession and care providers to people aged >65 Sample: 316 Descriptive statistical analysis	Awareness: temperature, hot weather impacts, risk factors Knowledge: thermo-regulation, heat-related illness, use of fans Practices: current, capacity to minimize illness, participation in specific strategies	Providing effective care can minimize heat-related risks and harms among the elderly	Low awareness of hot temperature (>30 °C): 13.3 % Higher awareness of protective factors than harmful factors (91.4 % vs. 78.9 %) Higher awareness among health professionals (over 90 %) than care providers/volunteers (80 %) Knowledge of thermoregulation: 62 % highest among nurses and GPs (>80 %), lowest among carers/volunteers (42.3 %) Knowledge of sweating: 9.2 % highest for GPs (27.3 %), lowest for carers/volunteers (1.8 %) Knowledge of heat-related illness: 22.7 % highest for GPs (63.6 %), lowest for carers/volunteers (13.5 %) Knowledge of use of fans: 5.2 % highest among care managers (13.3 %), lowest among nurse unit manages (2.4 %) Practice strategies: Distributing information (over 90 %); Seeking out homeless individuals (42 %); Organizing cooling shelters (36 %)	*Strengths* Study of care providers' awareness and practices in relation to heat Use of WHO's "awareness, knowledge, practice" framework *Weaknesses* Low response rate (29.5 %) Online survey subject to selection bias

Table 2 continued

Study	Location	Design	Independent variable/s	Outcome variable/s	Main findings	Assessment
Kalkstein and Sheridan (2007)	Phoenix—USA	Survey 21–24 Dec 2005 (winter) Sample: 201 aged ≥18 Descriptive analysis	Awareness of HWS Perceived danger of heat Perception of warnings	Behavioral change Actions and precautions taken as a result of heat warnings	>95 % were aware of HWS in Arizona Females, whites, over 30 yo and annual income >$20 k more likely to be aware of HWS Only near half of those who were aware of warnings issued changed their behavior Main behavioral changes: more fluids (83.3 %), avoid outdoors (66.7 %), stay indoors (64.3 %) other: avoid overexertion, dress appropriately, check elderly Main reasons for NOT changing behavior: "It's always hot" (42.5 %) other: heat does not affect me, inconvenience, did not hear warning, heat is not dangerous Hispanics (61.8 %) and aged >30 more likely to change behavior Higher perceived risk from heat associated with higher change of behavior (83.3 % of those who felt heat was VERY dangerous changed their activities) Worrying because of heat warning was associated with higher change of behavior (87.5 % very worried changed behavior)	*Strengths* Inclusion of younger age groups *Weaknesses* Lack of a theoretical framework Survey tool not tested/ piloted Small non-random sample Sampling bias toward women and shoppers Retrospective information subject to recall bias
Richard et al. (2011)	Montreal-Canada	Cross-sectional 238 middle aged and older with heart problems Phone or face-to-face Exploratory structural equation modeling	Perceived benefits of AC Perceived barriers to AC Perceived severity of heat Perceived susceptibility to heat Cues to action Health status	Use of AC during heatwaves	73 % had AC No significant socio-demographic difference between owners/non-owners During heatwaves: 68.1 % used AC often/always- 31.5 % occasionally/never. Average 14.5 h (SD = 9.4) Cues to action (sensitivity to heat), Perceived benefits and perceived barriers of AC use significantly associated with use/ non-use of AC during heatwaves Perceived severity of heat effects not associated with AC use	*Strengths* Use of a theoretical framework (HBM) although old High internal consistency among HBM constructs Diverse data collection method Reasonable sample size and high response rate *Weaknesses* Limited to a very specific group in one city
Semenza et al. (2008b)	Houston and Portland—USA	Cross-sectional Summer 2005 and 2006 Control vs. Advisory days Telephone survey Sample: 1962 Descriptive statistical analysis	Socio-demographic Feeling extremely hot	Cooling behavior, e.g., drink, AC use, dress Experiencing illness symptoms	Most respondents perceptive of extremely hot days Higher temperature associated with higher reports of dizziness, more pronounced in Portland Houston respondents three times more likely to use AC (90 % vs. 35 %). AC use in Portland positively correlated with income and age of home Perceived heat associated with more drinking (Portland and Houston), lighter dress, and change in exercise routines (Portland) Perceived heat correlated with: being female and lower education (Portland) lower education, lower income and non-white (Houston)	*Strengths* Large sample in 2 different locations Comparing advisory/ control days close to the event reducing recall bias *Weaknesses* Lack of a theoretical framework Survey tool not standard Sampling unclear Phone survey subject to bias toward phone owners, home stayers, and English speakers

Table 2 continued

Study	Location	Design	Independent variable/s	Outcome variable/s	Main findings	Assessment
Sheridan (2007)	Dayton, Philadelphia, Phoenix, Toronto- USA	Summers 2004 and 2005 Telephone Survey within 7 days post HWS issuance Sample: 908 aged ≥65 Descriptive analysis	Awareness of HWS: issuance, where, recalled recommendations	Behavior change	83 % aware of HWS in Toronto 90-92 % in other places Television the most common source of info (64–92 %); Radio in Toronto (40 %) and Phoenix (22 %); Newspaper in Phoenix (38 %) and Dayton (22 %); Friend/relative in Phoenix (17 %) Most heard the warning on the day or night before Recalling advice: avoid outdoors (59–79 %); keep hydrated (38–63 %); stay indoors or AC places (20–52 %) 25–47 % stayed indoors 9–17 % limited activities; 43–58 % drank more water; 6–32 % of drinkers drank less alcohol 30–47 % said cost was a factor in using AC 35–57 % behaved differently because of warning 52–66 % behaved differently than other hot days Reasons for not change of behavior: not hot enough; heat does not affect me	*Strengths* Fairly large sample Close to heat event reducing recall bias *Weaknesses* Lack of a theoretical framework Survey tool not standard Sampling unclear Phone survey subject to bias toward phone owners, home stayers, and English speakers
Wolf et al. (2010)	Norwich—UK	Qualitative 15 in-depth repeat interviews Summer 2007 and winter 2008	Perceived vulnerability to heat/cold → behavioral change Age ≥75	Effectiveness of Heat Wave Plan (2003) to protect vulnerable groups	Participants did not perceive themselves at risk, but perceived similar groups of people at risk Nothing can be done. Just put up with heat/cold Reactive, ad hoc measures, e.g., open window (heat) or wrap up (cold)	*Strengths* Qualitative study gaining in-depth information Perceptions/reactions to heat and cold compared *Weaknesses* Selection bias due to filtering by GPs Recall bias

AC Air-conditioner, *GPs* general practitioners, *HARS* heat alert and response systems, *HBM* health belief model, *HWS* heat warning system a telephone survey to collect data, the survey was likely to under-represent the poorest and most isolated sections of the society who may be even more influenced by the cost of running an air-conditioner, or not have access to them.

Discussion

Climate change has created many health challenges through events such as heatwaves (White-Newsome et al. 2009; Kjellstrom et al. 2010; Forastiere 2010; Künzli 2010). Heatwaves have harmful impacts on the physical and mental health, particularly of the more vulnerable groups such as the elderly, homeless and people with chronic diseases (Martiello and Giacchi 2010; Schwartz 2005; Kovats and Hajat 2008; Berry et al. 2010). While it is important to invest in long-term mitigation and adaptation plans such as improved buildings and environments (Braubach 2011; Cheng and Berry 2012), short-term or temporary action plans are also required to alleviate these harms. Six studies in this review showed that the implementation of HWSs is associated with reduced mortality. However, there is no clear evidence of their impact on morbidity, although one study did show a reduction in the number of ambulance dispatches (Weisskopf et al. 2002). Epidemiological studies confirm that some illnesses are caused or exacerbated as a result of exposure to extreme temperatures such as respiratory, cardiovascular, renal and diabetic conditions (Wang et al. 2012; Schwartz 2005; Kjellstrom et al. 2010). Furthermore, clinical and thermo-physiological studies corroborate that human body can adjust and acclimatize to normal hot weather conditions, but under excessively hot temperatures the body undergoes extreme stress, which the more vulnerable sections of the population may not be able to cope (WHO 2008). Therefore, one can reasonably infer that warnings and mitigation measures to reduce such exposure should alleviate the impacts of high temperatures.

There is evidence of a harvesting effect (or mortality displacement) that can explain, to some extent, the short-term reduction in mortality in the weeks following a heatwave, particularly among the sicker groups (Gosling et al. 2007; Hajat et al. 2005). Therefore, one limitation of the evaluations of HWS is that the effectiveness of these interventions may, at least partly, be explained by this harvesting effect, especially when several heatwaves occur in one season. The large scale mortality impacts of heatwaves such as the one in Europe in 2003 may also have had a longer lasting displacement effect, which could partly explain the reduced mortality of the 2006 heatwave. Future studies should take this into account. However, as studies have shown, the harvesting effect can only partly explain the reduced mortality as it varies from one location to another because of factors such as "temperature-mortality relationship sensitivity" (Gosling et al. 2007) and the population's health (Hajat et al. 2005). As such and in the absence of enough evidence, the costs of running these plans should be from a public health perspective considerably lower than the benefits gained by saving lives and reducing the use of emergency health services (Ebi et al. 2004).

None of the studies reviewed was able to establish a causal relationship between the adoption and implementation of HWS and reduced mortality or morbidity. The analytical techniques used in the studies generally compared the observed and expected mortality or use of emergency medical services between two heat periods, one with an HWS implemented and one without. The reductions in mortality and ambulance use in the heatwaves with HWS were attributed to the effective implementation of these systems. It is to be noted that in all of the localities, the issuance of heat warnings and advisories were in conjunction with the introduction of a range of different mitigating responses and interventions. Therefore, associating the reduction in mortality (or morbidity) to the effectiveness of HWS also incorporates the effectiveness of these response programs. Since the type, extent of availability and utilization of these responses varied from one study to another, we cannot infer which measures were more effective than others.

In addition to the importance of having action plans and physically implementing them, the effectiveness of the HWS depends on many other factors, as they involve a complex interplay of human perceptions and behaviors as they interact with the social world. These policies may have limited impact if the human factor is not taken into consideration (Bassil and Cole 2010). Issuing heat advisories and warnings is not sufficient as they may not lead the people to change their behavior (Kovats and Ebi 2006). The studies addressing the second question confirmed this. Most of these studies showed that while awareness of heat and heat-related dangers was high, particularly among older age groups, such awareness did not necessarily translate into change of behavior.

Many cities and localities around the world have implemented heat action plans following an episode of severe heatwave in the past two decades, but not all people who are considered as "vulnerable" utilize the facilities introduced during such extreme events. The evidence reviewed here corroborates the significance of individual perceptions as major determining barriers to utilizing the provided services. Many may see it as another naturally hot summer season and would rely on "common sense" to protect themselves or people they care for. It was indicated that perceived threat to self or others of heat was more likely to push the individuals to take actions for themselves or others. However, taking such actions may be limited by

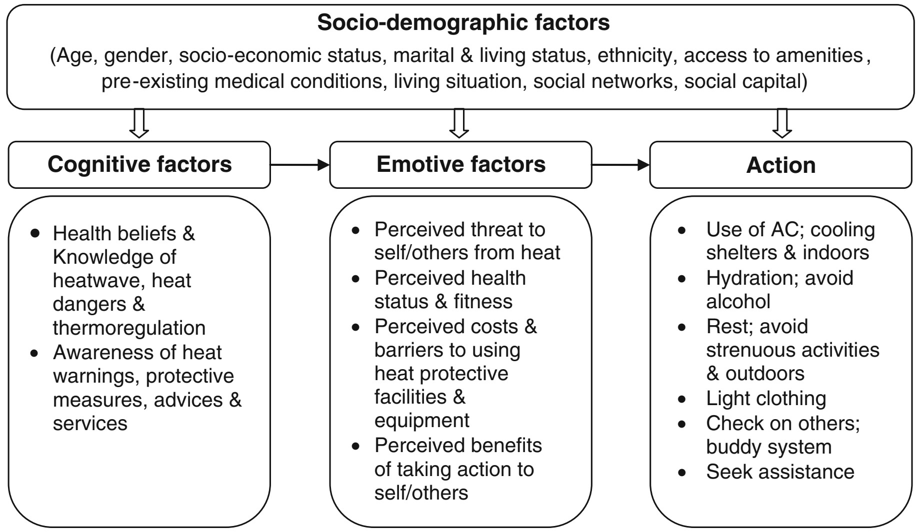

Fig. 2 Synthesis of factors affecting the likelihood of taking heat protection actions

the perception of the costs involved (such as in running air conditioners) as opposed to benefits gained, and accessibility and feasibility of taking appropriate actions (such as difficulty in reaching a cool place) to protect against adverse heat effects.

While the findings in these studies were overall consistent, we acknowledge that the findings are difficult to generalize due to the small number of the studies and some methodological weaknesses. For instance, most studies were conducted in single locations and/or with small samples, and some had problems with establishing a representative sample due to selection bias. Data collection was also subject to issues such as the use of non-standard or non-tested survey tools and recall bias. A major issue with a few of the quantitative studies was lack of a relevant theoretical framework to guide and explain the findings.

Knowledge gap

The number of studies in this area is limited. Furthermore, differences in designs and methods make it impossible to synthesize and conduct a meta-analysis of the effectiveness of HWSs. Also, the warnings are combined with action plans and different intervention measures in different localities. Therefore, results are not directly comparable due to differences in the type and extent of interventions triggered in association with HWS, making it even more difficult to pinpoint which programs are more effective in reducing heat-related health impacts.

While some studies addressing the second question used relevant theories such as the Health Belief Model or components of the Health Service Utilization Model (Bernard and McGeehin 2004; Richard et al. 2011; Kalkstein and Sheridan 2007; Wolf et al. 2010), the theoretical soundness of others is ambiguous. Further research using appropriate theories, such as cognitive and health promotion theories, can strengthen the research findings and shed light on understanding and interpreting human behavior. Inspired by the Health Belief Model and Health Service Utilization Model (Glanz et al. 2008) and the Precaution Adoption Process model (Weinstein et al. 1998; Weinstein 1988), Fig. 2 synthesizes the socio-demographic, cognitive and emotive factors and their relation with taking protective actions against heat dangers.

Further research is also necessary to determine the particular interactions of environmental, social and clinical factors that together contribute to the increased risk of adverse health outcomes (e.g., mortality or morbidity). This would then permit the more effective design of public policy responses so that they better target these factors.

Conclusion

Even though no single study can establish a causal relationship, the weight of evidence demonstrates the benefits of the adoption and implementation of HWS across different areas. Thus, from a public health and policy perspective, the existing evidence supports the effectiveness of HWSs and response plans in reducing heat-related mortality (and potentially morbidity). However, further research is needed to establish which measures and programs are more cost-effective in reducing the adverse health impacts. Furthermore, the evidence indicates that certain sections of the community may benefit more from these plans if their needs and perceptions are taken into consideration. More research is recommended into ways of improving the utilization of services by the vulnerable populations and groups during heatwaves. This review also highlights the benefits of using theoretical frameworks to enhance our understanding of human behavior in this area.

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Conflict of interest At the time of conducting the study, KV was a Principal Scientist at the Queensland Department of Environment and Resources Management, which partly funded this project. The department has since been restructured and KV is now affiliated with the Queensland Department of Science, Information Technology, Innovation and Arts.

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