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REVIEW

Sex differences in mortality after heat waves: are elderly women at higher risk?

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Abstract

Background and objective Climate change leads to more frequent, intense and longer-lasting heat waves which can have severe health outcomes. The elderly are a high-risk population for heat-related mortality and some studies suggested that elderly women are more affected by extreme heat than men. This study aimed to review the presence of sex-specific results in studies performed on mortality in elderly (> 65 years old) after heat waves in Europe.

Methods A literature search was conducted in July 2017 on papers published in databases Pubmed and Web of Science between January 2000 and December 2016.

Results 68 papers that included mortality data for elderly after heat waves were identified. The 13 of them which presented results distinguished by sex and age group were included in the review. Eight studies showed worse health outcome for elderly women compared to men. One study showed higher mortality rates for men, two found no sex differences and two studies presented inconsistent results.

Conclusion Studies that present sex-stratified data on mortality after heat waves seem to indicate that elderly women are at higher risk than men. Future research is warranted to validate this finding. Furthermore, a better understanding on the underlying physiological or social mechanisms for possible sex and gender differences in excessive deaths for this vulnerable population is needed to set up appropriate policy measures.

Keywords Heat waves · Sex differences · Elderly · Mortality · Gender

Introduction

Mainly due to human actions global mean surface temperature increased by 0.85 °C from 1880 to 2012, and temperature is expected to rise faster in the twenty-first century under all assessed greenhouse gas emission scenarios (IPCC 2014). Regional surface warming will in general lead to more frequent, intense and longer-lasting heat waves that are often intensified in cities due to the urban heat island effect (Oke 1973; Meehl and Tebaldi 2004). There is no universal definition of a heat wave, but it is often referred to as a period of consecutive days with maximum (and minimum) temperatures excessively hotter than normal (Perkins and Alexander 2013). Despite the lack of a clear definition, heat waves have been known to have severe impacts on human health and mortality (Beniston et al. 2007). A recent study showed that heat-related fatalities might increase 50 times from reference the period 1981–2010 to 151,500 deaths a year in 2071–2100 in the European population (Forzieri et al. 2017). Heat waves will account for 99% of the future weather-related disaster death toll by the end of the twenty-first century (Forzieri et al. 2017).

Physiological risk factors for heat-related deaths include chronic health conditions such as cardiovascular, pulmonary and mental illnesses; polypharmacy; and lower fitness levels. Socio-economic and behavioural factors that increase the risk of dying during a heat wave include living alone; being unable to care for oneself; having a lack

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of mobility; living on the top floor; lack of air conditioning; and reluctance to change behaviour during a heat wave (Vandentorren et al. 2006; Bouchama et al. 2007; Hansen et al. 2011). Having multiple risk factors, elderly have been reported to be a major risk group for heat-related mortality in several reviews (Bouchama et al. 2007; Kovats and Hajat 2008; Basu 2009; Åström et al. 2011; Kenney et al. 2014).

Due to aging, the cardiovascular response during passive heating alters and also individual risk factors such as poor aerobic fitness and chronic health conditions that may reduce the ability to cope with extreme heat are highly present among the elderly population (Pandolf 1997; Minson et al. 1998; Sawka et al. 2011). A striking observation is that elderly males and females do not seem to suffer equally from the effects of extremely high outdoor temperatures. Excessive heat-related deaths are reported in both men and women in different studies, although overall women often seem more affected by heat waves than men (Basu 2009; Åström et al. 2011). Differences between men and women in vulnerability towards extremely high (and lasting) temperatures may be due to physiological dissimilarities or other factors such as age or social structure (Kyselý et al. 2011). While discussing differences in moratlity between men and women it is important to make a distinction between sex and gender. We here make use of the definitions of the World Health Organization (WHO) which regards sex as the biological and physiological characteristics of males and females. Gender is defined as the socially constructed characteristics of men and women, which differ between societies and can be changed over time (World Health Organization 2011).

Europe is a high-risk area for heat-related deaths due to its growing elderly population and high density of population and buildings (United Nations 2015). The proportion of the population aged 60 years or over in Europe will increase to over 30% in 2050. Furthermore, the sex ratio is skewed with only 50 men per 100 women at ages above 80 (United Nations 2013). Due to aging societies, women are going to represent an even larger sub-population of the elderly in the upcoming years. Next to this, extremely hot weather is relatively uncommon in a lot of European countries, which makes its population even more vulnerable to heat waves (Kovats and Kristie 2006).

Preventive strategies controlled by (local) governments can reduce heat-related impacts on human health, however, it is essential for these preventive actions to address them to the right persons who are most vulnerable in a heat wave (Haines et al. 2006; O'Neill et al. 2009). No recent reviews have been performed on sex differences in mortality after heat waves for the elderly. If elderly women are truly at higher risk, more awareness for this sub-population in public health programs is warranted. We therefore performed a literature search on European studies showing differences in mortality between males and females during prolonged periods of extreme heat, published in the years 2000–2016.

Methods

Eligibility criteria

In this review, articles presenting mortality rates or relative risk of dying after heat waves or extremely hot days were included. Data of subjects must be presented as a (sub) population of elderly humans aged 65 years and over. Only non-intervention studies such as time series, case–crossover or (retrospective) cohort studies that provided appropriate effect estimates [e.g., mortality following heat waves, relative risks (RR), odds ratios (OR) or regression coefficients] were included. The search was limited to studies performed in European countries published from January 1st 2000 to December 31st 2016. Only peer reviewed journal papers with original data and written in English were used.

Information sources

Studies were retrieved from databases Pubmed and Web of Science. The search was built on three sub-domains which were (1) heat waves/high temperature; (2) mortality and; (3) elderly. The primary search used the Medical Subject Headings (MeSH)-terms "hot temperature", "extreme heat", "heat stress disorders", "aged", "aged, 80 and over", "elderly", "mortality" and "hospital mortality". Next to the MeSH terms title and abstract were scanned for the words "heat wave", "heatwave", "urban heat island", "heat stress", "heat flux", "high ambient temperature", "elderly" and "hospitalization". Some authors were contacted for additional data when, e.g., results stratified by sex and age groups were presented separately, but not combined. However, this did not result in usable data.

Search strategy

Search outcomes for both databases were imported to Refworks and checked for duplicates (Fig. 1). First a title and quick abstract scan were performed to exclude irrelevant papers not mentioning mortality, heat waves (or extreme temperatures), or studies that were not performed in Europe. Then, abstracts were fully analysed and papers were excluded based on non-matching study design. Full-text of residual papers was analysed and papers not describing specific mortality results after heat waves in elderly were excluded. We then checked if resulting studies looked at sex-specific outcomes. Studies which presented results separate for men and women were included in the final step. Next to the computerized database search,

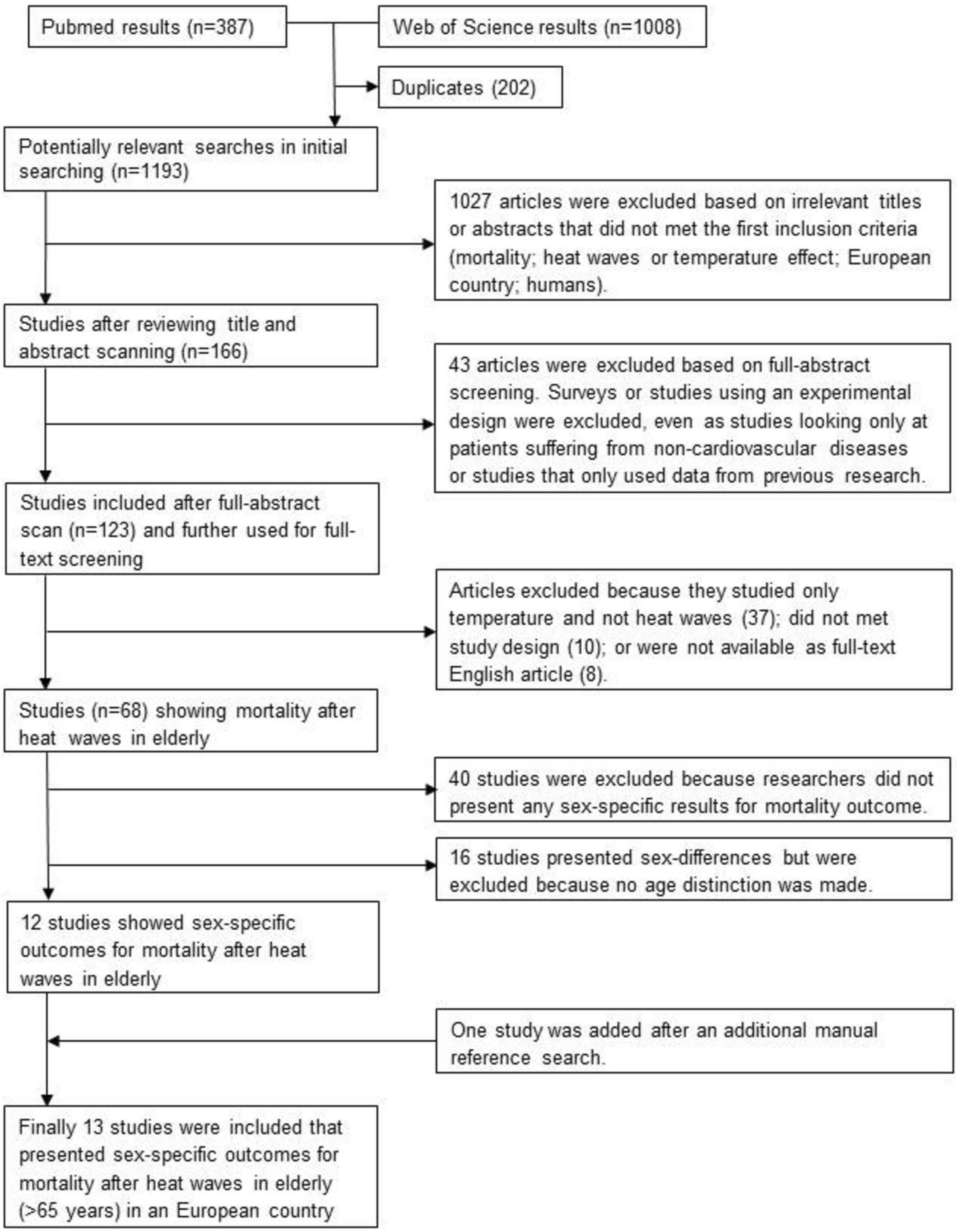

Fig. 1 Literature selection process for the computerized database search

the reference sections of included studies were searched and appropriate references that were not initially identified were added. Additionally, references of published literature reviews on heat-related mortality were checked manually.

Results

In total, 1193 studies were screened (Fig. 1). 116 of them were assessed for eligibility after a title and abstract scan. Of the 68 studies that showed mortality after heat waves in elderly, 40 did not present sex-specific results and 16 studies made no age distinction in their sex-specific results. Finally, 12 studies were included. Furthermore, one study was found after the additional reference list search (Hutter et al. 2007). Characteristics of the 13 studies meeting all inclusion criteria are summarized in Table 1.

Worse female health outcome

During the 2003 heat wave in Paris (France), being female was an independent risk factor for excess death (adjusted OR [95% CI] = 1.43 [1.11–1.83]) (Canoui-Poitrine et al. 2006). The effect of the same heat wave was studied for the whole of France, and women showed over-all higher 'expected versus observed' mortality ratios than men in all age groups above 65 years old (Fouillet et al. 2006). Excessive mortality ratios [95% CI] were highest in the above 75 age groups; 1.5 [1.4–1.6] for males and 1.8 [1.7–2.0] for females. Age correction lessened the effect of sex but could not fully explain differences between men and women. When equal ages were considered, mortality rates were still 15% higher for females. During the summers of 1971–2003, six heat waves were identified in France (Rey et al. 2007). Except for the one in 1976, all heat waves showed higher mortality ratios for women above 65 than men in the same age group. However, it was only found to be statistically significant in 2003 when age- and sex-standardized mortality ratios for elderly above 75 were 28% higher for women compared to men.

In Galicia (Spain), the effects of two heat waves in 1990 and 2003 were analysed (DeCastro et al. 2011). In this study, average mortality exceedance was about 1.5 times higher in elderly females compared to males. Higher female mortality was also present in Belgrade (Serbia) where an excessive mortality rate of 54% was observed for elderly women, compared to a 23% increase for males during a heat wave in July 2007 (Bogdanovic et al. 2013).

The effect of heat waves on mortality in elderly in nine European cities was analysed during the summers in 1990–2004 (D'Ippoliti et al. 2010). Elderly women showed higher mortality rates in all age groups in both North continental and Mediterranean cities. However, a significantly higher impact of heat waves on all-cause mortality (% increase [90%CI]) for women (33.0 [28.9–37.3]) compared to men (18.1 [14.2–21.9]) was only found in Mediterranean cities in the 75–84 age group. In a study performed in four Italian cities, women had a higher probability of dying than men in all age groups (Stafoggia et al. 2006). The largest difference was observed in the 75–84 age group with odds ratios [95% CI] of 1.28 [1.18–1.40] for men and 1.44 [1.30–1.59] for women. Finally, an Austrian study showed a higher relative risk of dying [95% CI] for elderly women (1.15 [1.10–1.21], $P < 0.001$) compared to males (1.08 [1.02–1.14], $P = 0.009$) in Vienna during the years 1998–2004 (Hutter et al. 2007).

Worse male health outcome

One Swedish study showed that men were more affected by heat waves than women showing odds ratios [95% CI] of 1.046 [1.015–1.078] and 1.009 [0.982–1.036], respectively, for ages above 65 in Stockholm County (Rocklöv et al. 2014).

Studies without sex differences or inconsistent results

In 2006, excessive death rates were analysed in France, and women and men above 75 showed nearly the same observed versus expected mortality rates of, respectively, 1.09 and 1.08 (Fouillet et al. 2008). The same study showed that (even for the elderly) excess mortality was greater for women, but we do not endorse this conclusion given the small difference and the fact that this study did not adjust for age, nor presented any confidence intervals. Another French study found higher mortality rates for elderly men (2.5%) compared to women (1.6%) residing in Paris during the 2003 heat wave (Belmin et al. 2007). This study showed an adjusted OR of 1.52 (95% CI 1.16–2.01, $P = 0.0029$) for being male compared to female. However, no sex differences in mortality were observed for institutionalized residents.

In the Catalonia region in Spain, the effect of extremely hot days was examined for the years 1983–2006 (Basagaña et al. 2011). Excessive mortality was most common among the elderly, but no sex differences were found after adjustment for age. In another Spanish study, the rise in deaths/day due to a one temperature rise above 36.5 °C was calculated in Madrid (Díaz et al. 2002). In the 65–75 age group, risk was higher for males (1.65, $P < 0.001$) than for females (1.07, $P < 0.01$). However, in the > 75 age group the rise in deaths/day after a one temperature rise above 36.5 °C on excess deaths was higher in females (8.15, $P < 0.001$) compared to males (2.51, $P < 0.01$). Next to this, the percentage contribution of the heat wave effect on daily mortality was higher for women than for men in both age groups. It was most pronounced in the age group above 75 with contributed death rates of 28.4% for women compared to 12.6% for men in deaths with organics causes.

Discussion

Summary of findings

This review was performed to systematically examine the presence of sex-specific results in European studies

Table 1 Characteristics of studies reporting sex-specific results on mortality after heat waves in elderly

Study ID	Location and period	Design	Heat wave definition	Age groups	Outcome variable	Effect estimates [95% CI]	Key findings
Basagaña et al. (2011)	Catalonia region, Spain. Warm seasons of 1983–2006	Case-crossover study	Extremely hot days: days with maximum temperature above the 95th percentile	Age groups divided per 10 years: (< 1; 1–10; 11–20; …; 81–90; > 90)	Excessive mortality	Relative risk (RR)	No sex differences were observed after adjustment for age
Belmin et al. (2007)	Five departments in the Paris area (Ile-de-France). 1–20 August 2003	Retrospective cohort study	Heat wave France 2003[a]	82.0 ± 9.2 years for community dwellers and 84.6 ± 9.4 for institutionalized residents	Mortality odds ratio in elderly	Adjusted OR: 1.30 [1.10–1.54] for being male compared to female, $P = 0.0022$	More deaths occurred in men compared to women for community dwellers, but no differences were found in institutionalized residents
Bogdanovic et al. (2013)	Belgrade, Serbia. July 2007 heat wave	Case-crossover study	Period of at least three consecutive days in which the maximum temperature exceeds 35 °C	Mean age of death ± SD for $M = 73.06 \pm 12.13$ and $F = 74.95 \pm 11.85$	Excessive mortality	Rate (%) of excessive deaths were 23% for males and 54% for females	Women were more severely affected by the heat wave than men
Canoui-Poitrine et al. (2006)	Paris, France. 1–20 August 2003	Case-crossover study—logistic regression model	Heat wave France 2003[a]	77.2% ($N = 727$) of those who died were ≥ 75 years old	Excess mortality (people who died at home)	Adjusted OR = 1.43 [1.11–1.83] for being female (M: OR = 1)	Being female was an independent risk factor for excess death in a period of heat wave compared to the reference years
DeCastro et al. (2011)	Galicia, Spain. 1987–2006	Time series—ARIMA	> 3 consecutive hot days (24 h period with a maximum temperature exceeding the long-term daily 95th percentile)	All above 65, but no mean average was given	Excessive mortality	–	Mortality exceedance was ~ 1.5 times higher for females
Díaz et al. (2002)	Madrid, Spain 1986–1997	Time series—ARIMA	Any day on which the maximum temperature exceeded 36.5 °C	Elderly aged 65–75 years old and above 75	Mortality	Rise in deaths/day due to one temperature rise above 36.5 °C. 65–75: $F = 1.07$, $P < 0.01$; $M = 1.65$, $P < 0.001$ and > 75: $F = 8.15$, $P < 0.001$; $M = 2.51$, $P < 0.01$	For organic deaths heat waves contributed more to mortality in women, especially in the age group above 75

Table 1 (continued)

Study ID	Location and period	Design	Heat wave definition	Age groups	Outcome variable	Effect estimates [95% CI]	Key findings
D'Ippoliti et al. (2010)	Athens, Barcelona, Budapest, London, Milan, Munich, Paris, Rome, Valencia. Summers 1990–2004 and 2003, separately	Case-crossover design	(1) Periods of at least 2 days with maximum apparent temperature exceeding the 90th percentile (2) Periods of at least 2 days in which Tmin exceeds the 90th percentile	Age groups: 65–74; 75–84; and > 85	Increased mortality	The effect of heat waves on daily mortality (% increase and 90% CI) was 18.1 [14.2–21.9] for males compared to 33.0 [28.9–37.3] for females aged 75–84	A statistically significant higher impact among females than males was observed in Mediterranean cities in the 75–84 age group. A higher susceptibility of females was found after stratifying by age groups
Fouillet et al. (2006)	France. August 1st to November 30th, 2003	Time series—log linear Poisson model	Heat wave France 2003[a]	Age groups: 65–74; ≥ 75; 75–84; 85–94; and ≥ 95	Excessive mortality	Observed/expected mortality ratio was 1.5 [1.4–1.6] for males and 1.8 [1.7–2.0] for females above 75	Higher observed versus expected mortality rates were found for women. Age correction lessened the effect but did not completely explained differences in sex
Fouillet et al. (2008)	France. 11–28 July 2006	Poisson regression model	Heat wave France 2006[b]	Age groups: all ages; 55–74; and ≥ 75	Excessive mortality	Observed/expected mortality ratio 1.09 for females and 1.08 for males above 75	The excess mortality and excess mortality deficit were greater for women, also in the elderly
Hutter et al. (2007)	Vienna, Austria. 1998–2004	Generalized additional model (GAM) with Poisson deviates and log-link	Consecutive period of at least 3 days during which the daily maximum temperature is ≥ 30.0 °C	Age groups: all ages, babies (< 1 year) and elderly (> 65 years)	Excessive mortality	RR of dying on a heat wave day for females 1.15 [1.10–1.21, $P < 0.001$] compared to 1.08 [1.02–1.14, $P = 0.009$] for males	Increase in deaths was stronger in females compared to males, however this was not more pronounced in the elderly compared to the total population
Rocklöv et al. (2014)	Stockholm County, Sweden. 1990–2002	Time stratified case-crossover design	A period of 1 or more days with maximum temperature above the 98th percentile	Age groups: < 65 and ≥ 65	Mortality odds ratios	OR associated with heat wave duration: 1.046 [± 0.031] for men and 1.009 [± 0.027] for women above 65	Men experience stronger impacts from longer heat wave duration for ages 65 and above

Table 1 (continued)

Study ID	Location and period	Design	Heat wave definition	Age groups	Outcome variable	Effect estimates [95% CI]	Key findings
Rey et al. (2007)	France. Summers (June–September) of 1971–2003	Time series: log linear Poisson regression model	Periods of at least 3 consecutive days when maximum and minimum temperature are above 95th percentile	Age groups: < 1; 1–34; 35–44; 45–54; 55–64; 65–74; 75–84; 85–94; ≥ 95	Excessive mortality	%(O–E) excess deaths as a percentage of overall excess mortality, only presented in figures and no data shown	Except for the year 1976 mortality rates were higher in females compared to males of the same age group in all age groups above 65, but only significant in 2003
Stafoggia et al. (2006)	Bologna, Milan, Rome, and Turin (Italy) 1997–2003	Case-crossover study	Extremely hot days were after effect calculation defined to be above 30 °C	Age groups: 35–64; 65–74; 75–84; 85–94; 95≥	Risk of dying on days with 30 °C in mean apparent temperature (lag 0–1) versus days with 20 °C	Risk of dying at days of 30 °C ambient temperature versus 20 °C odds ratio for men 1.28 [1.18–1.40] and women 1.44 [1.30–1.59] from 75 till 84 years old	The odds ratios for women were higher than for men in each age category

M Male, *F* female

[a]Between 4 and 18 August 2003, average daily temperatures across France exceeded 35 °C (Le Tertre et al. 2006)

[b]In the 2006 heat wave in France, daily temperatures reached 35 °C and night-time temperatures were above 20 °C until July 28th when temperatures began to drop (Fouillet et al. 2008)

analysing mortality data after heat waves in elderly. From 68 studies presenting mortality statistics in the data-driven search, 56 did not present mortality rates for men and women separately in the age group above 65 years old. We included 13 studies in this review. The majority of these papers (8) provide data that support the hypothesis that elderly women are more vulnerable during heat waves than men. Mortality rates in women were sometimes twice as high as those reported in males (Bogdanovic et al. 2013). Next to this study, higher risks for women were observed in two of the three studies performed after the 2003 heat wave in France (Canoui-Poitrine et al. 2006; Fouillet et al. 2006), one study in France looking at the effect of mortality after six heat waves (Rey et al. 2007), one Spanish study (DeCastro et al. 2011), a study after mortality in four Italian cities (Stafoggia et al. 2006), an Austrian study (Hutter et al. 2007), and a study in nine European cities (D'Ippoliti et al. 2010). One study showed a more severe outcomes for men after heat waves (Rocklöv et al. 2014). Two studies could not confirm the presence of any sex differences (Fouillet et al. 2008; Basagaña et al. 2011) and finally the other two studies showed inconsistent results regarding male and female mortality after heat waves (Díaz et al. 2002; Belmin et al. 2007).

Influence of age

To appreciate these findings some explanations for the sex differences need to be addressed. Given that European women generally become older than men (Austad 2006; Leon 2011), worse health outcomes after a heat wave may partly be explained by the fact that the mean age of females in a particular age group is higher than the average age of the males. The fact that women live longer than men does make them more vulnerable in periods of excessive heat since, as stated above, aging is associated with increased mortality during heat waves. One study included in this review found a 75% higher excess mortality for women compared to men after the heat wave in 2003. Indeed, age did play an important role and adjustment for age did reduce the sex difference. However, when equal ages were considered there still was a female excess mortality of about 15% in the age group above 55 years (Fouillet et al. 2006). Four other studies that were included in this review also adjusted for age. In two of them worse health outcomes for females remained after adjustments (Canoui-Poitrine et al. 2006; Rey et al. 2007), one found higher mortality rates for men (Belmin et al. 2007), and one study did not find any differences between males and females (Basagaña et al. 2011). Most studies therefore seem to indicate that the differences in risk between men and women cannot be fully explained by differences in age.

Biological differences in coping with excessive heat

During a heat wave, problems arise when the body is unable to lower its temperature by vasodilatation and perspiration. This can cause severe health outcomes including heat syncope, heat exhaustion, heat cramp and heat stroke (Knochel 1989). Heat stroke is associated with a systemic inflammatory response leading to a syndrome of multi-organ dysfunction, which becomes life threatening when core temperature exceeds 40 °C (Bouchama and Knochel 2002; Glazer 2005). There are several possible physiological explanations for the difference in capability of women compared to men in dealing with heat stress. These include the lower capacity to sweat and release heat due to lower fitness levels, higher body fat percentage, a poorer acclimatization ability, and a different skin conductance for women (Shoenfeld et al. 1978; Kenney 1985). Also comorbidities such as cardiovascular and pulmonary diseases increase the risk of dying during a heat wave (Semenza et al. 1996; Bouchama et al. 2007; Rosano et al. 2007). Premenopausal women have a lower risk for cardiovascular diseases compared to men of the same age, but this sex advantage seems to disappear gradually when women become older (Yang and Reckelhoff 2011). Higher numbers of cardiovascular events are observed in postmenopausal women compared to premenopausal women of the same age, although in some studies this effect disappears after adjustments for, e.g., smoking (Kannel et al. 1976; Atsma et al. 2006). The menopause and the accompanying change in reproductive hormones, such as a decrease in estrogen levels, can adversely affect cardiovascular fitness and specifically alter heat dissipation in elderly women (Tankersley et al. 1992; Charkoudian 2003; Rosano et al. 2007). During a heat stroke, leakage of endotoxins and increased levels of (anti-)inflammatory cytokines such as TNF-α, Interleukin-1 (IL-1) and Interleukin-6 (IL-6) may interfere with thermoregulation (Bouchama and Knochel 2002). Estrogen levels and receptors have been associated with inflammatory responses and estrogen is thought to inhibit several cytokines involved in thermoregulation and coagulation (Selzman et al. 1998; Baker et al. 2003). Postmenopausal changes in estrogen levels may partly explain why especially elderly women experience worse health outcomes during a heat wave, although still a lot remains to be unknown about the precise role of estrogen during heat stress.

Another effector mechanism that is important in body temperature regulation is the increase of antidiuretic hormone (ADH) and aldosterone in the blood (Segar and Moore 1968; Koppe et al. 2004). A study examining the secretion of ADH in healthy elderly showed that plasma ADH levels were always a twofold higher in males than in female subjects (Asplund and Aberg 1991). Hormonal changes that come with aging may cover a part of the observed sex differences in health outcome during heat waves. However, still a lot remains to be unknown about the complex interactions of the male and female body with extreme heat, which needs further examination.

Socio-cultural factors influencing vulnerability

Not only biological issues, but also gender-related components play a role in the increased vulnerability of elderly women. An important social risk factor that contributes to this susceptibility is the fact that elderly women often live alone because of losing their partners (Utz et al. 2002). Physical and social isolation is observed to be highly associated with heat-related death in the United States (Naughton et al. 2002; Klinenberg 2015). However, the effect of living alone was not found to be significant in a study in England and Wales (Hajat et al. 2007), nor in France (Bouchama et al. 2007). Attention has been given to the fact that social capital may positively influence individual adaption toward climate changes (Pelling and High 2005). However, a British study concluded that strong social networks may enhance instead of reducing the vulnerability of elderly people during heat waves (Wolf et al. 2010). People did not realize that high temperatures would be a significant threat to them, and strong bonding networks would rather uphold than question these thoughts. Other gender-related issues that may influence mortality rates during heat waves are exposure to heat and physical activity during heat waves. In the elderly, women are more active in the household than men, as shown in a Dutch elderly population (Van Den Hombergh et al. 1995). Since taking rest from both indoor and outdoor activities is a way to deal with extreme heat, women could be at higher risk for heat-related illnesses and mortality when they do not alter their activity behaviour (Sampson et al. 2013). However, regular physical activity during, e.g., the performance of household chores may also reduce the risk of declining physical health, which could result in an overall benefit of being active (Penedo and Dahn 2005). Also time spent outside in high temperatures may have adverse health effects (Green et al. 2001). Yet, there is not much known about gender differences in outdoor activities among the elderly.

Also the traditional role of the women as caretaker for the children, and the men as wage earner may influence susceptibility of dying during a heat wave in later life. Widows are financially disadvantaged when looking at personal income compared to men and never-married women (Holden and Smock 1991; Utz et al. 2002). Low income has been associated with increased mortality effects of high temperature in both European and US studies (Whitman et al. 1997; Naughton et al. 2002; Stafoggia et al. 2006). Financial status may provide an explanation for higher mortality rates in elderly women, also because of the fact that low socio-economic status has been associated with poorer quality housing and a lack of air conditioning (Koppe et al. 2004; Bouchama et al. 2007). Next to income, differences in race and ethnicity may influence the access to medical care and mortality rates (Mayberry et al. 2016; van Doorslaer et al. 2006). However, the complex interactions between gender, race and mortality after heat waves still have to be further analysed.

Strengths and limitations

This is the first time that sex differences in mortality in elderly after heat waves were analysed systematically, taking into account papers published over a long time span. The review showed that elderly females are often at higher risk compared to men and this seems to become more pronounced when age increases, for example in age groups above 75. However, some studies showed worse health outcomes for men and there may be several reasons for inconsistencies observed among the studies. First, researchers make use of different heat wave definitions and studies relate to different age groups, which makes comparison between studies more difficult. Also, the effect of a heat wave may be overestimated because of short-term mortality displacement (harvesting) of ill or vulnerable people who would have died anyway in the succeeding days (Hajat et al. 2006). Researchers do not always account for this lag effect of heat waves, which is highly recommended to be considered (Anderson and Bell 2009). Also, the variety in study types makes it more complicated to compare results. For example, higher mortality rates were observed in men among community dwellers in five Paris areas (Belmin et al. 2007). However, this is the result of a retrospective cohort study with people receiving stipend specifically allocated to dependent subjects of 60 years of age or older. Therefore, it is hard to generalize these results to the entire elderly population. Also, studies were performed in different areas and countries. Next to this, potential modifying factors such as humidity and atmospheric pollution warrant more attention since temperature extremes modify the effects of air pollutions like O3 and PM10 on both cardiovascular and non-causal mortality (Li et al. 2017). In this review, only four of the included studies controlled for air pollution (Díaz et al. 2002; Stafoggia et al. 2006; D'Ippoliti et al. 2010; Rocklöv et al. 2014). However, it is worth further examining these modifying factors to better understand what is driving the observed sex differences in mortality. For example, (elderly) women are more vulnerable to die than men from both ozone and PM_{10} pollution (Bateson and Schwartz 2004; Medina-Ramon and Schwartz 2008). This could contribute to the observed sex differences in mortality after heat waves. An important limitation is the fact that most studies looking at mortality after heat waves did not present mortality rates for men and women separately. Therefore, it is hard to draw general conclusions from the papers that were finally included, as they only represent a small size of the total available literature on this topic. As stated above, most included studies did not adjust for age which could result in higher mortality rates for elderly women. Also many studies did not adjust for other confounders such as socio-economic status or comorbidities. Besides, (excessive) mortality values were sometimes given without confidence intervals or p values, which complicate comparison between males and females.

Recommendations for future research

Future research should be focused specifically on sex differences, using statistical models with sex (or gender) as determinant for mortality, whereby researchers correct for other confounding factors like age. Next to this, more subgroups of people vulnerable to dying during a heat wave should be defined, and in these subgroups, sex and gender differences must be examined. Attention should be given both to individual physiological characteristics such as pre-existing (chronic) diseases as well as socio-economic and cultural factors such as income that all may influence susceptibility to heat stress. Prevention programs can specifically target elderly women, if future studies confirm that they are more vulnerable than men. Heat health warning systems can be beneficiary when implemented locally and developed with involvement of the system's end users (Kovats and Kristie 2006). Taking care of the elderly living alone may reduce their susceptibility to heat waves, as well as improvements in care and the indoor environment of nursing and care homes (Hajat et al. 2007). Further research after the underlying physiological or socio-cultural mechanisms causing increased vulnerability to heat stress could give a starting point for effective preventive actions. Researchers have been working on heat vulnerability indexes (HVIs) to spatially locate populations with increased vulnerability to heat (Reid et al. 2009; Johnson et al. 2012; Wolf and McGregor 2013). A review was performed on 15 studies concerning heat vulnerability assessments and the authors concluded that HVIs are useful to target the intervention of heat risk (Bao et al. 2015). Striking is the fact that only two studies included being male or female as a variable during the assessments. This supports our finding that there is still too little attention for sex as a determinant for vulnerability during heat waves.

Conclusion

Climate change will lead to more frequent and intense heat waves that will particularly affect the elderly population. This review showed that elderly women are more prone to die from heat waves than men. Future research explicitly focussed on sex differences in mortality outcomes after excessive heat should be performed to validate this finding. Sex (or gender) must be taken as an independent variable and age correction is needed to correct for the higher longevity of elderly females. If women are at higher risk, preventive actions can be targeted specifically on this sub-population.

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