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Exploring the association between heat and mortality in Switzerland between 1995 and 2013

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ABSTRACT

Designing effective public health strategies to prevent adverse health effect of hot weather is crucial in the context of global warming. In Switzerland, the 2003 heat have caused an estimated 7% increase in all-cause mortality. As a consequence, the Swiss Federal Office of Public Health developed an information campaign to raise public awareness on heat threats.

For a better understanding on how hot weather affects daily mortality in Switzerland, we assessed the effect of heat on daily mortality in eight Swiss cities and population subgroups from 1995 to 2013 using different temperature metrics (daily mean (Tmean), maximum (Tmax), minimum (Tmin) and maximum apparent temperature (Tappmax)), and aimed to evaluate variations of the heat effect after 2003 (1995–2002 versus 2004–2013).

We applied conditional quasi-Poisson regression models with non-linear distributed lag functions to estimate temperature-mortality associations over all cities (1995–2013) and separately for two time periods (1995–2002, 2004–2013). Relative risks (RR) of daily mortality were estimated for increases in temperature from the median to the 98th percentile of the warm season temperature distribution.

Over the whole time period, significant temperature-mortality relationships were found for all temperature indicators (RR (95% confidence interval): Tappmax: 1.12 (1.05; 1.18); Tmax: 1.15 (1.08–1.22); Tmean: 1.16 (1.09–1.23); Tmin 1.23 (1.15–1.32)). Mortality risks were higher at the beginning of the summer, especially for Tmin. In the more recent time period, we observed a non-significant reduction in the effect of high temperatures on mortality, with the age group > 74 years remaining the population at highest risk.

High temperatures continue to be a considerable risk factor for human health in Switzerland after 2003. More effective public health measures targeting the elderly should be promoted with increased attention to the first heat events in summer and considering both high day-time and night-time temperatures.

1. Introduction

Exposure to high ambient temperature is associated with increased mortality risk and thus poses a public health concern. In recent years, several studies have reported that both high temperatures and heat waves can cause excess mortality (Baccini et al., 2008; Basu, 2009; D'Ippoliti et al., 2010; Kovats and Hajat, 2008; Xu et al., 2016) and lead to increased morbidity (Michelozzi et al., 2009; Ye et al., 2012). The temperature-mortality relationship has been shown to be heterogeneous across countries and regions due to different climates, heat sensitivity, population characteristics and adaptation measures (Gasparrini et al., 2015a, 2015b; Hajat and Kosatky, 2010). In cities, populations are potentially more affected by extreme temperatures than those in the surrounding area, especially during the night, as built environments absorb and store heat, known also as the urban heat island effect (Gronlund, 2014; Kovats and Hajat, 2008). On the individual level, potential factors that have been documented to modify the vulnerability to heat-related mortality include sex, age, education and socioeconomic status (Benmarhnia et al., 2015; Gronlund, 2014). Especially the elderly, people with pre-existing chronic diseases and small children have been identified as vulnerable population groups (Kovats and Hajat, 2008; Schifano et al., 2009; Xu et al., 2012).

Previous studies have evaluated the temperature-mortality association with different temperature metrics and varying thresholds of defining a hot day (e.g. absolute and relative temperatures) (Lubczyńska et al., 2015; Xu et al., 2016). Temperature parameters that are mostly used to describe mortality risk of temperature include daily maximum, daily mean and bio-meteorological indices such as apparent

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temperature, a metric that also takes into account humidity (Ye et al., 2012). Other studies found some evidence that high night-time minimum temperatures, also in combination with high day-time temperatures, lead to excess deaths (Vicedo-Cabrera et al., 2016a). Although, according to previous research, no single temperature measure was found to be superior to the others to predict mortality (Barnett et al., 2010), differences in duration and magnitude of the implied effect may vary across geographical regions (Zhang et al., 2014) and susceptible subgroups. Thus, understanding the effects of the different temperature metrics in a given area is crucial in assessing the temperature-mortality relationship and for designing and evaluating adaptation measures.

In the recent years, authorities have introduced adaptation measures to minimize harm in susceptible population groups and to prevent heat-related mortality. In Europe, such programs have been developed and expanded especially after the devastating heat wave in summer 2003 for which about 70,000 excess deaths were reported (Robine et al., 2008). Previous research has indicated that interventions such as heat action plans (HAP) – generally consisting of early warning systems, timely public and medical advice, and strategies to improve adaptation to hot weather – are successful in reducing heat- and heat wave-related health effects (Benmarhnia et al., 2016; Chau et al., 2009; Ebi et al., 2004; Fouillet et al., 2008; Morabito et al., 2012; Schifano et al., 2012). However, although the public attention to heat changed after the summer 2003 in Europe, a study by de'Donato et al. (2015) found no decrease in attributable deaths to extreme temperatures in cities with populations that are less used to extreme summer heat in the years after 2003 (1996–2002 versus 2004–2010). In fact, in Europe, a stronger attenuation of the mortality impact associated with hot weather was observed in cities and countries with moderate and Mediterranean climates in recent years (de'Donato et al., 2015; Gasparrini et al., 2015a).

In Switzerland, the 2003 heat wave caused an estimated 6.9% increase in all-cause mortality (Grize et al., 2005) and as a consequence, the Swiss Federal Office of Public Health developed an information campaign to raise public awareness on heat threats and provided information material for health professionals and vulnerable populations on how to behave during heat waves. Health authorities in some but not all Swiss counties and cities implemented additional public health measures including early alerts for health professionals and intensified care of susceptible individuals with critical heath conditions and limited social interaction during heat waves. However, it is not clear how such measures have affected heat-related mortality in Switzerland. A recent analysis of the hot summer 2015 found an estimated 5.4% increase in all-cause mortality between 1 June and 31 August (Vicedo-Cabrera et al., 2016b).

The aims of this study were to assess the effect of heat on mortality in eight Swiss cities from 1995 to 2013. Doing so, we used different temperature metrics to identify potential differences in effect estimates in the total population and different subgroups. Additionally, to evaluate variations of the effect of heat on mortality after the heat wave 2003 and subsequent public health interventions, we compared the mortality risk estimates between the two time periods 1995–2002 and 2004–2013.

2. Methods

2.1. Study setting

Eight main Swiss cities were included in the analyses (Fig. 1). Cities are located in the German (Basel, Berne, Lucerne, St. Gallen, Zurich), French (Geneva, Lausanne) and Italian (Lugano) speaking part of Switzerland. To increase the study area of the Italian speaking area South of Switzerland, the urban communities near Lugano with similar altitudes (≤ 280 m above sea level) were also included in the analyses and added to the city of Lugano. All cities are located within an altitude range between about 200 and 700 m above sea level. The French and Italian speaking cities belong to counties (Geneva, Vaud, Ticino) that have implemented heat warning systems targeted to vulnerable populations after the hot summer 2003 (FOPH, 2017).

2.2. Mortality data

Daily mortality data registered in the eight Swiss cities between 1995 and 2013 were obtained from the Federal Office of Statistics, Switzerland. We restricted the analyses to non-external deaths other than accidents (International Classification of Diseases, 10th revision (ICD-10) codes A00-R99, V01-V99, W00-X59) occurring during the warm season (May to September). For this study, city-specific counts of daily deaths were computed for the total population, and separately for males and females, and for two age classes (≤ 74 years, > 74 years).

2.3. Meteorological data

For each city, meteorological data from a representative monitoring station of the Swiss Monitoring Network (SwissMetNet) was used. We obtained the meteorological data from the Federal Office of Meteorology and Climatology (MeteoSwiss). We chose the maximum daily apparent temperature (Tappmax) as main temperature indicator for our analysis. It is a measure to describe the discomfort resulting from combined heat and high humidity. This index was computed for each day and station using hourly mean temperatures (T) and the corresponding hourly mean dew point temperature (Tdewpoint) based on the following formula: $-2.653 + 0.994 \times (\text{T in C}^{\circ}) + 0.0153 \times (\text{Tdewpoint in C}^{\circ})^2$ (Kalkstein and Valimont, 1986). To compare the effect of alternative temperature metrics on mortality, we also considered daily maximum temperature (Tmax), daily minimum temperature (Tmin) and daily mean temperature (Tmean).

2.4. Statistical analyses

2.4.1. Comparison of temperature indicators

We performed an aggregated exposure case-crossover analysis at city level to explore the overall heat-related mortality. Conditional Poisson regression models accounting for overdispersion were used to estimate the relationship between each of the four temperature indicators (Tappmax, Tmax, Tmean and Tmin) and daily mortality during the warm season (May-September) between 1995 and 2013. Conditional Poisson regression models provide an alternative to time-stratified case-crossover analyses of time series data. It is computationally less intensive than the conditional logistic models and it can allow for overdispersion or auto-correlation in the original counts (Armstrong et al., 2014). All cities were pooled into one dataset. A bidirectional time-stratified approach was used to properly control for long-term and seasonal trends. Each case day was matched with its control days according to the year, month, and day of the week within each city-specific series by including in the conditional Poisson regression model a stratum variable. Temperature was introduced in the models as a cross-basis function describing the non-linear and delayed effect of temperature. Specifically, we applied distributed lag non-linear models (DLNM) (Gasparrini, 2011; Gasparrini et al., 2010) to estimate a common exposure-response function over all cities using a quadratic B-spline with two internal knots placed at the 75th and 95th percentiles of the warm season temperature distribution, and a lag-response function using a natural cubic spline with three equally spaced internal knots on the log-scale. A maximum lag of six days was used since previous research showed that the heat effect usually lasted for a week (Grize et al., 2005) and to account for short-term harvesting. The model parameters were chosen based on preliminary analyses and previous work (Gasparrini et al., 2015a).

The association between temperature and daily mortality was explored by computing the overall cumulative exposure-response

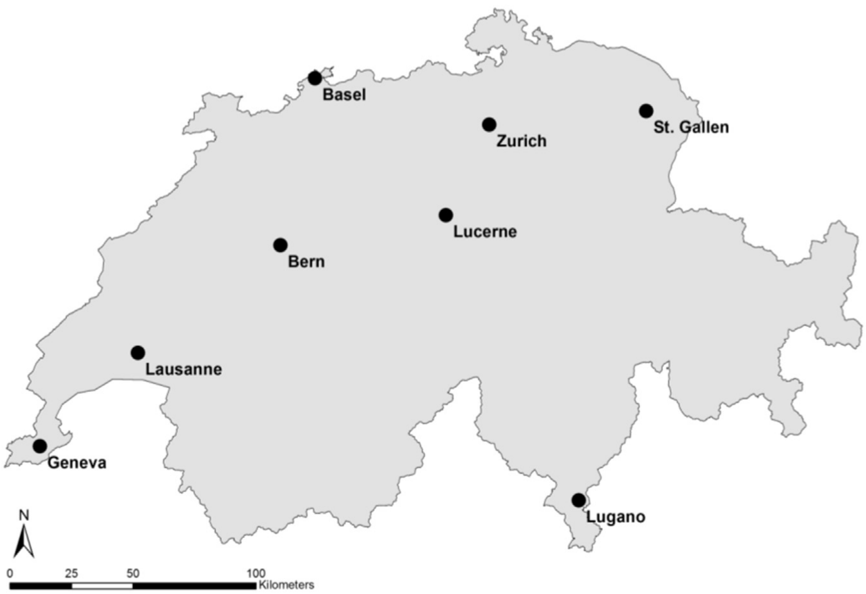

Fig. 1. Map of Switzerland showing the eight cities included in the study.

association in terms of relative risk (RR) over the whole lag period (lags of 0–6 days) using the median temperature of the warm season across all cities as reference. As our focus was heat-related mortality, the data were analysed for each temperature parameter to compare the estimated relative risks at very hot days. *A priori*, hot days were defined as the 98th percentile (P98) of the warm season temperature distribution using the pooled data of all cites. The respective values were 32 °C for Tappmax, and Tmax, 25 °C for Tmean and 20 °C for Tmin. Similarly, the rounded median was computed for each of the four temperature parameters, using the measurements of all eight cities and they equalled 21 °C, 22 °C, 17° and 13 °C, respectively. Despite climatic differences between some of the cities, we chose to use the same reference and exposure values for each city as it simplifies the interpretation of results in the small country of Switzerland.

For the potential effect modifiers at the individual level and to identify the susceptible subpopulations, we applied stratified models to examine whether the effect of temperature differed by gender and age class (≤ 74 years, > 74 years). Additionally, as previous research indicated that the excess mortality at the beginning of the warm season is more pronounced than in the end of the summer (Gasparrini et al., 2016), we also computed effect estimates for early (May and June) and late summer (July to September). To test whether the obtained results are robust to modelling choices, we carried out a sensitivity analysis by changing the parameters of both the exposure-response function (position of knots) and the lag response-function (number of knots).

2.4.2. *Comparison of temperature-mortality relationship of two time periods*

To assess whether public awareness and public health interventions contributed to reduce heat-related mortality in the urban population of Switzerland, the mortality risk estimates of two time periods (1995–2002 versus 2004–2013) were compared using Tappmax as temperature indicator. Analyses were run separately for each time period to estimate the period-specific effect on daily mortality during the week following a hot day (P98 of summer Tappmax before/after 2003: 31 °C/32 °C) using the period-specific median Tappmax (21 °C in both time periods) as a reference. The year 2003 was excluded from this analysis because it was an exceptional year in terms of heat-related mortality.

As a sensitivity analyses, we assessed the cumulative exposure-response association between Tappmax and mortality for each city by considering both city-specific and period-specific (1995–2013, 1995–2002, 2004–2013) reference temperatures instead of computing pooled estimates over all cities and using the overall median summer Tappmax of all cities.

All analyses were conducted with R software (version 3.2.0). The *dlnm* package was used to fit the DLNMs (Gasparrini, 2011).

3. Results

Table 1 describes the series of daily mortality in the eight Swiss cities during the whole study period 1995–2013, and the number of daily deaths during the warm season for the cities before and after the year 2003. Mean daily deaths (± standard deviation) during the period 1995–2002 were slightly higher than from 2004 to 2013 (before 2003: 4.3 (3.4); after 2003: 3.8 (2.9)).

There was modest variability in temperature distributions between the cities in the period 1995–2013 (Fig. 2). City-specific median and P98 Tappmax ranged between 18–24 °C and 29–34 °C, respectively. The warmest temperatures were registered in Lugano, located in the southern part of Switzerland, and the coldest temperatures in St. Gallen in eastern Switzerland. Compared to the overall median (21 °C) and P98 (32 °C) of the pooled Tappmax distribution across all meteorological stations, the respective city-specific values in Lugano and St. Gallen were about 2–3 °C warmer and colder, respectively. The cities with the

Table 1
Daily mortality during May-September for the whole study period (1995–2013) and for the time periods before and after the year 2003 in the study area.

Time-period	1995–2013		1995–2002	2004–2013
Characteristics	Total deaths	Mean daily deaths (range)	Total deaths	Total deaths
Total deaths	*94,301*	*4.1 (0 −26)*	*42,018*	*46,955*
Cities				
Geneva	10,333	3.6 (0 −12)	4400	5327
Lausanne	8118	2.8 (0 −11)	3723	3958
Lugano	10,910	3.8 (0 −12)	4505	5783
Basel	14,722	5.1 (0 −17)	6676	7167
Bern	10,838	3.7 (0 −11)	4898	5370
Lucerne	5846	2.0 (0 −8)	2527	3004
St. Gallen	5179	1.8 (0 −8)	2275	2635
Zurich	28,355	9.8 (0 −26)	13,014	13,711
Age categories				
≤ 74 years	26,948	1.2 (0 −12)	12,908	12,558
> 74 years	67,353	2.9 (0 −22)	29,110	34,397
Sex				
Male	41,958	1.8 (0 −12)	18,837	20,801
Female	52,343	2.3 (0 −22)	23,181	26,154

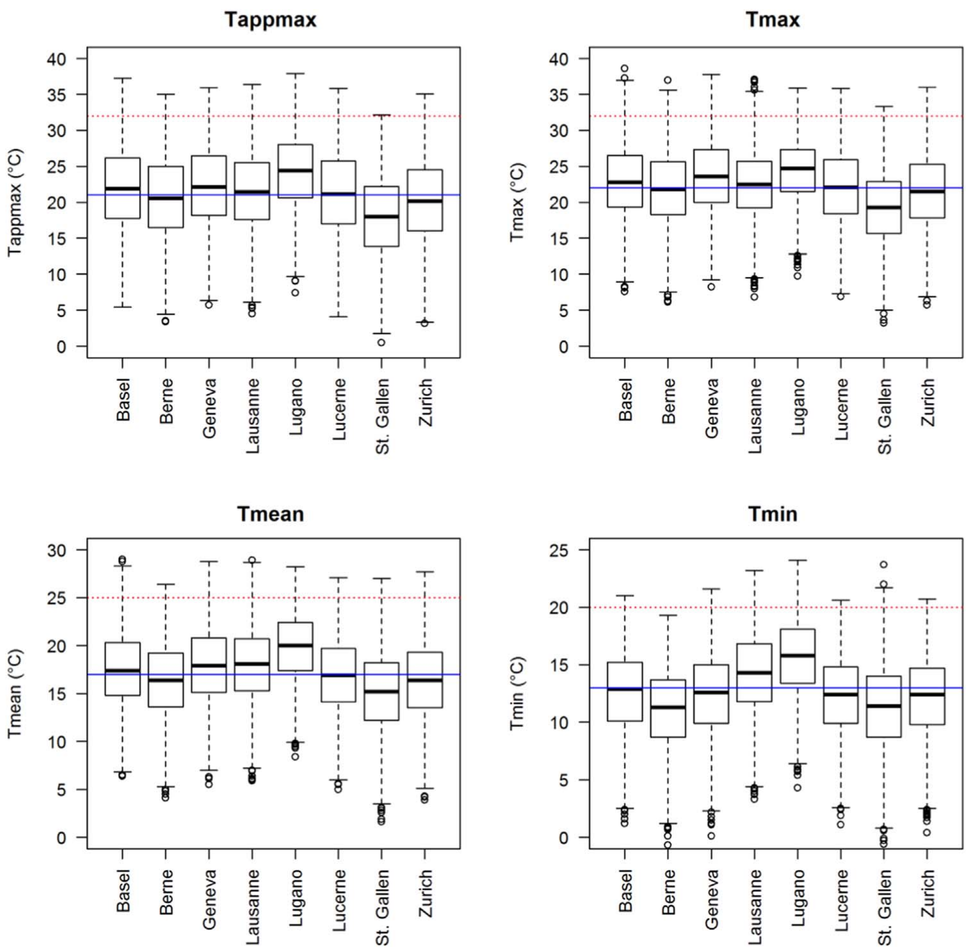

Fig. 2. Boxplots of daily maximum apparent temperature (Tappmax), daily maximum temperature (Tmax), daily mean temperature (Tmean) and daily minimum temperature (Tmin) by city during summer 1995–2013. The blue horizontal line represents the overall median temperatures; the red dotted horizontal line represents the overall 98th percentile.

highest P98 of Tmin were Lugano and Lausanne. Comparing the Tappmax in the time periods before and after 2003, the P98 have increased on average by 1.1 °C (range: 0.8–1.6 °C) in the most recent period, with the highest increase observed in Lausanne (1.6 °C) followed by Basel (1.5 °C), Lugano (1.3 °C) and Geneva (1.2 °C). Changes in P50 Tappmax were below 1 °C in all cities.

Fig. 3 presents the cumulative exposure-response association between mortality and Tappmax over the total lag period and the lag-specific RR at P98 with the median Tappmax as reference during the warm season (May-September) for the whole study period. Daily mortality risk increased slowly with temperature and escalated rapidly after about 31 °C. Over the following week (lags of 0–6 days), Tappmax was significantly associated with a 12% increase in mortality risk (RR: 1.12 (95% CI: 1.05; 1.18)) when it reached P98 (Table 2). The highest relative mortality risks were observed between lag0 and lag2 with the most pronounced risk occurring on a hot day itself (lag0) (RR: 1.07 (1.04; 1.10)). City-specific plots of the relationship between Tappmax and mortality (Supplementary Fig. S1) using city-specific P50 temperatures as reference show that the RR increased mainly above 32 °C in all cities, except in the city of Berne and St. Gallen that are the coldest cities.

We observed similar temperature-mortality associations for Tappmax, Tmax and Tmean, and found some differences for Tmin. The RR was highest for Tmin over the total lag period of one week (Table 2) as well as on the actual day of a heat event ($RR_{lag0} = 1.14$ versus 1.07, 1.07 and 1.10 for the P98 of Tappmax, Tmax and Tmean, respectively)

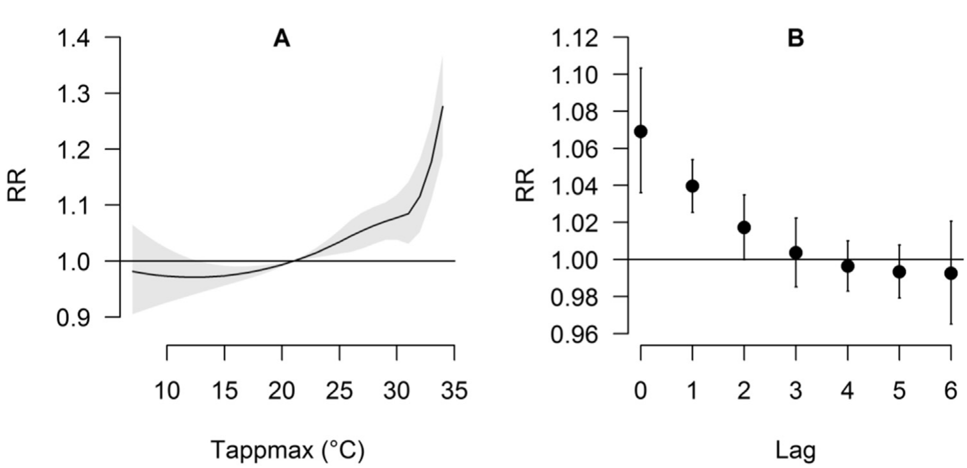

Fig. 3. Association between daily maximum apparent temperature (Tappmax) and daily mortality between 1995 and 2013: Cumulative exposure-response association with 95% confidence interval over one week (lags of 0–6 days) (A) and lag-specific relative risk (RR) estimates with 95% confidence interval at the 98th percentile (32 °C) (B), using the median value of the overall summer temperature distribution (21 °C) as reference.

Table 2
Cumulative relative mortality risk estimates associated with Tappmax, Tmax, Tmean and Tmin in the total population, subgroups and for early and late summer 1995–2013[a].

	Tappmax		Tmax		Tmean		Tmin	
	RR	(95% CI)	RR	(95% CI)	RR	(95% CI)	RR	(95% CI)
Total population	1.12	(1.05; 1.18)	1.15	(1.08; 1.22)	1.16	(1.09; 1.23)	1.23	(1.15; 1.32)
≤ 74 years	1.04	(0.93; 1.16)	1.07	(0.95; 1.20)	1.07	(0.96; 1.20)	1.11	(0.98; 1.25)
> 74 years	1.15	(1.07; 1.23)*	1.18	(1.10; 1.27)*	1.19	(1.11; 1.28)*	1.29	(1.19; 1.39)*
male	1.03	(0.94; 1.12)	1.07	(0.98; 1.18)	1.09	(1.00; 1.19)	1.16	(1.05; 1.28)
≤ 74 years	0.98	(0.83; 1.14)	1.02	(0.87; 1.20)	0.99	(0.84; 1.16)	1.05	(0.89; 1.25)
> 74 years	1.15	(1.01; 1.30)	1.17	(1.03; 1.33)	1.16	(1.02; 1.32)	1.21	(1.06; 1.39)
female	1.19	(1.10; 1.28)*	1.22	(1.12; 1.32)*	1.21	(1.12; 1.32)*	1.30	(1.19; 1.42)*
≤ 74 years	1.16	(0.95; 1.41)	1.10	(0.90; 1.35)	1.08	(0.88; 1.32)	0.96	(0.77; 1.20)
> 74 years	1.18	(1.07; 1.30)	1.22	(1.10; 1.34)	1.22	(1.11; 1.35)	1.28	(1.15; 1.43)
Early summer[b]	1.30	(1.15; 1.48)	1.30	(1.15; 1.47)	1.31	(1.17; 1.47)	1.40	(1.22; 1.61)
Late summer[c]	1.08	(1.00; 1.18)*	1.11	(1.02; 1.21)*	1.09	(1.00; 1.19)*	1.13	(1.03; 1.24)*

Tappmax: daily maximum apparent temperature; Tmax: daily maximum temperature; Tmean: daily mean temperature; Tmin: daily minimum temperature; RR: Relative mortality risk; CI: Confidence Interval.

[a] Associations are expressed as cumulative heat effect over the following week (lag0-6) when temperature reached the 98th percentile of the summer temperature distribution using the median temperature as reference.

[b] May-June.

[c] August-September.

* Chi-squared test of effect modification provided significant results for age ≤ 74 years vs. > 74 years ($p < 0.05$ for Tmin and $p < 0.2$ otherwise), male vs. female ($p < 0.05$ for Tappmax and Tmax and $p < 0.2$ otherwise) and early vs. late summer ($p < 0.05$).

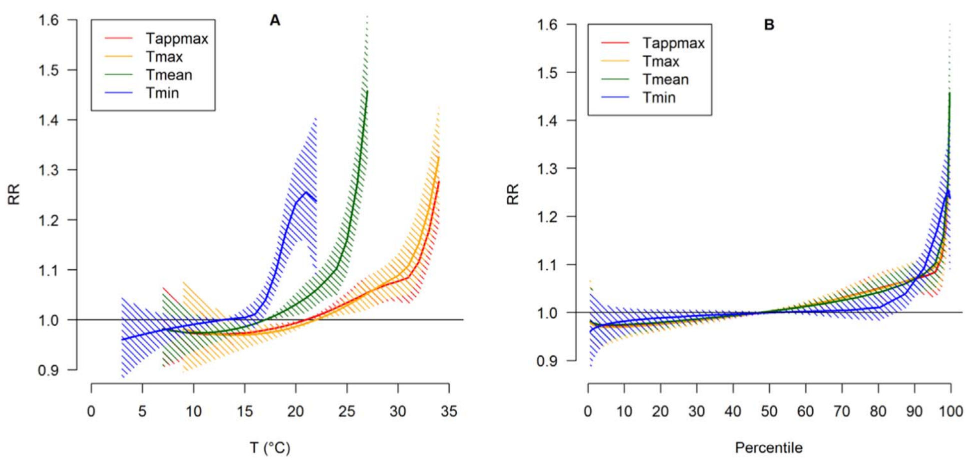

Fig. 4. Comparison of cumulative exposure-response associations with 95% confidence intervals over one week (lags of 0–6 days) of different temperature metrics (Tappmax: daily maximum apparent temperature; Tmax: daily maximum temperature; Tmean: daily mean temperature; Tmin: daily minimum temperature) with absolute values (A) and relative values (B) using the median value of the overall summer temperature distribution as reference.

(Supplementary Fig. S2). Additionally, we observed a different cumulative temperature-mortality relationship along the temperature range for Tmin than for the other temperature metrics as illustrated in Fig. 4B showing the RR against the percentiles of the temperature distributions. The mortality risk associated with Tmin increased only at very high temperatures (above the 90th percentile, i.e. 18 °C). In contrast to Tappmax, Tmax and Tmean, no change in RR was observed for Tmin below the 80th percentile, that is about 16 °C.

In the analyses stratifying by various individual-level factors, the heat effects were found to vary by sex and age (Table 2). Across all temperature metrics and considering the whole range of temperatures above the median summer value, the cumulative heat effect was higher in older than younger people and stronger in women than men. The greatest risk was observed among females aged > 74 and for Tmin. Plots of stratified temperature-mortality relationships and lag-specific results by subgroup are shown for Tappmax in the Supplementary Material Fig. S3–6. Especially at very high temperatures, the increase in RR with temperature was higher in women than men (Fig. S3). We also observed a different pattern of RR along the range of lags in men and women in terms of level and persistence of effects (Fig. S4). In men, the risk of dying was largest on the hot day itself (assessed with all temperature metrics) and remained significant solely on the day after a hot day (lag1). Subsequent RRs below 1 suggest harvesting, a short-term mortality displacement of vulnerable individuals (Gasparrini et al., 2010). For women, the heat effect was rather constant over two (Tmin), three (Tmean) and four days (Tappmax, Tmax) after a hot day. These patterns were particularly pronounced for men and women > 74 years old (Supplementary Fig. S5, S6). For younger men, the RR was only significantly increased on the hot day itself (RR Tappmax: 1.10 (1.02; 1.18)). The observed differences between subgroups did not change when changing the model specifications in the sensitivity analyses.

We observed a significantly higher susceptibility to heat in the first two summer months than in the late summer (Table 2). Whereas, in early summer high Tmin values seem to increase RR most strongly, the effect was similar among the four temperature parameters during the second part of the warm season.

A decrease of the mortality risk associated with extreme temperatures was observed in the time period following the hot summer in 2003 (Fig. 5). Table 3 shows the estimated overall cumulative RR at the P98 of Tappmax for the total population and by age class separately for the two time periods. We observed a non-significant (p-value > 0.2) reduction in the effect of high temperatures on mortality risk in both age classes, with the population > 74 years remaining the population at highest risk after 2003. City-specific plots of the cumulative exposure-response associations between mortality and Tappmax over the total lag period depict that the reduction of RR at high summer temperatures are mostly attributable to the three cities that have implemented heat warning systems (Lugano, Lausanne and Geneva) (Supplementary Fig. S7).

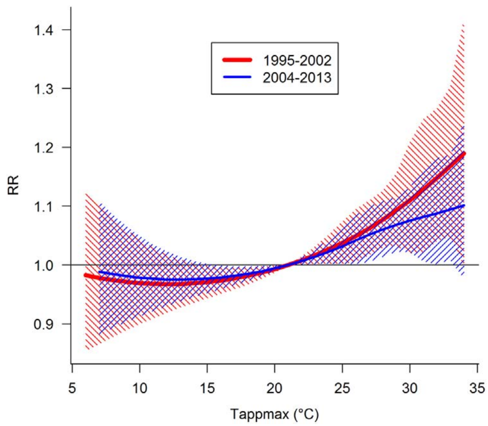

Fig. 5. Cumulative (lags of 0–6 days) exposure-response associations with 95% confidence intervals between relative mortality risk (RR) and heat for and daily maximum apparent temperature (Tappmax) before and after the year 2003.

Table 3
Cumulative relative mortality risk (RR) estimates associated with daily maximum apparent temperature (Tappmax) before and after 2003[a].

		Tappmax	
	Time period	**RR**	**95%CI**
Total population	Before 2003	1.13	(1.02; 1.25)
	After 2003	1.09	(1.00; 1.18)
≤ 74 years	Before 2003	1.09	(0.91; 1.29)
	After 2003	1.02	(0.86; 1.20)
> 74 years	Before 2003	1.15	(1.02; 1.30)
	After 2003	1.11	(1.01; 1.23)

[a] Associations are expressed as cumulative heat effect over the following week (lag0-6) when temperature reached the 98th percentile of the time period-specific summer temperature distribution using the median temperature as reference.

4. Discussion

We assessed temperature-mortality associations in Switzerland using data from eight cities and different temperature indicators. Overall, heat had a significant effect on mortality during the time period 1995–2013 using all temperature indicators. The strongest increase in mortality risk was found on the actual day of a heat event (defined as the P98 of the summer temperature distribution), especially for Tmin. Comparing the time periods before and after the year 2003, a reduction in the effect of high summer temperatures on mortality risk was observed in the more recent period mostly attributable to the three cities that have implemented heat warning systems.

Mortality was significantly associated with all temperature metrics during the period 1995–2013. However, for very hot temperatures, i.e. above the 90th percentile and on the hot day itself, the strongest increase in RR was found for Tmin. This finding is consistent with other studies arguing that the human body can cope less with heat when temperatures are not cooling down during the night to more agreeable temperatures following a hot day (Hajat and Kosatky, 2010; Havenith, 2005). Based on our stratified analyses for early and late summer, this seemed to be especially true for early summer. The change in the association between temperature and mortality during the summer may be related to short-term acclimatization and mortality displacement (Gasparrini et al., 2016). An additional explanation for the somewhat higher RR associated with Tmin than Tappmax, may be the fact that household air conditioning is less common in Switzerland than in European countries of warmer climates for which a smaller heat effect has been reported for Tmin than for Tmean and Tmax (Lubczyńska et al., 2015). Thus, people can escape less from high temperatures during night. Future studies are warranted that disentangle the immediate and delayed effect of these highly correlated temperature metrics.

We found the highest mortality risk in elderly women when considering lagged effects of heat. Also other European studies have reported a higher susceptibility of females to heat (D'Ippoliti et al., 2010; Fouillet et al., 2006; Schifano et al., 2009) and have attributed this finding to physiological reasons, such as a reduced sweating capacity affecting the ability to cope with heat stress, and to social conditions of elderly women living alone. Interestingly, on the actual day of a heat event, we detected a higher susceptibility to daily maximum temperatures in males of both age classes. Also, the subsequent harvesting effect was more pronounced in men than in women. Among other factors, this short-term increase in risk may be explained by gender differences in the behavior on a hot day. As women tend to exhibit a better health-seeking behavior than men (Smith et al., 2006), they may have followed the recommendations on how to behave during a hot day more carefully than men in our study population.

Compared to other, mostly multi-country, studies on heat-related mortality risk (de'Donato et al., 2015; Gasparrini et al., 2015a, 2015b), we chose to use the same definition of a hot day for all cities in the small country of Switzerland. It is also in line with the current national strategy of having the same heat wave definition for the whole country. This assumes that there is no variability in the adaptive capacity of the populations to heat within urban Switzerland even though some cites are exposed more frequently to hot temperatures. Our results support the current public health policy as we observed the strongest impact of heat on mortality above 32 °C in all cities.

After 2003, we observed the strongest decrease in the effect of high temperatures on mortality in the city of Lugano and Lausanne which are among the warmest cities in Switzerland. Also, both cities are exceptional within Switzerland in a way that they belong to counties that are more active in promoting public health measures to prevent adverse health effects of hot weather (FOPH, 2017, assessed based on a personal survey). Thus, the population awareness of health risks associated with heat may have enhanced more profoundly in these two cities than in other areas. The city of Geneva has implemented a similar policy and risk reduction after 2003 was seen for moderate hot days but not the very hot days. In Basel, where the temperature was also higher than the overall median, no clear decrease in mortality risk was observed. However, the 95%CIs are large especially in the upper temperature ranges and it has to be assessed in more detail and with larger sample sizes by city or county whether the reduction of mortality risk is indeed attributable to such public health measures by also taking into account other risk factors for heat-related mortality such as socio-economic status and differences related to the built environment favoring urban heat islands. Additionally, the strategies to improve adaptation and reducing adverse health effects of heat waves in Switzerland after 2003 are not totally random but related to language region (restricted to French and Italian speaking areas of Switzerland). This indicates heterogeneous public health policies in different parts of Switzerland, involving other prevention activities such as the ban of smoking in public places (Vicedo-Cabrera et al., 2016c), which might have influenced the general susceptibility to heat-related effects.

Some limitations must be acknowledged. Temperature was measured only at a single station per city. Thus, within-city variability of temperature could not be accounted for. By considering only deaths that occurred in the main Swiss cities and did not include suburban or rural areas (except for Lugano where we included the urban communities of similar altitude), we attempted to minimize exposure misclassification. However, further studies with improved exposure assessments taking into account potential small-scale differences in temperature between and within cities are warranted. Also, beside the city, no information on the home location of the death cases was available. Thus, neighborhood socio-economic status, which has been shown to potentially affect the temperature-mortality relationship (Benmarhnia et al., 2016, 2015), could not be included in our study.

As in other European cities (de'Donato et al., 2015; Fouillet et al., 2008; Schifano et al., 2012), this study shows that heat continued to be a significant public health risk in Swiss cities after 2003, especially among the older population and females. Although we found some reductions in heat-related mortality risk after 2003, a recent study on the all-cause excess mortality during the hot summer 2015 in Switzerland concluded that estimates for 2015 (5.4%) were only a little lower compared to those of summer 2003 (6.9%) (Vicedo-Cabrera et al., 2016b). Summer 2015 was the second warmest summer for 150 years in Switzerland with a heat wave in July similar in magnitude but less prolonged than the heat wave in August 2003. This may indicate that in particular for extreme heat conditions mitigation measures to prevent heat-related mortality in Switzerland have not become noticeably effective in the last 10 years, in particular in the German part of Switzerland. As heat waves became more frequent and severe in the last decades, a trend that is likely to continue in the context of climate change (IPCC, 2013), it is important to both understand how temperature affects health in a given area and to evaluate the effectiveness of public health interventions in reducing heat-related mortality. Further evaluations of the specific measures and their effectiveness are recommended to justify future investments. As mortality was associated with all temperature metrics, but most strongly with Tmin, we suggest that future heat warning systems consider both high daily maximum and minimum temperatures.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.envres.2017.07.021.

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