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5. Health, Morbidity, Mortality

Mortality and the heat waves 2003 and 2006 in Switzerland
A story about vulnerability[*]

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Abstract

The literature shows considerable geographic heterogeneity in terms of mortality responses to heat. We use meteorological information, mortality data linked to the Census-enumerated elderly population of urban Switzerland and land-use statistics to model the effect of heat on mortality in a multilevel perspective. This allows the simultaneous consideration of individual, contextual and environmental factors which are susceptible to influence heat-related mortality. The independent effect of heat on mortality during the summer months 2001-2006 was small in Switzerland. When living in elderly or care institutions, elderly were found to be more at risk than when compared to those living in private dwellings. However, heat attenuated rather than exacerbated socioeconomic differentials of mortality at the individual and contextual level. Environmental amenities – such as green areas and the density of the built environment – tended to mediate the mortality effect of physical exposure to heat, although not significantly. This analysis mainly emphasises the protective role of behavioural adaptation at the individual level.

Introduction

Although heat waves have a long history, it was in 1995 that temperature peaks emerged as 'new social risks' on the political agenda. Indeed, in July of that year approximately 750 heath-related deaths occurred in Chicago over a period of just five days. Eric Klinenberg's 2002 book *Heat wave: A Social Autopsy of Disaster in Chicago* became a bestseller since in 2003 Europe was also hit by a similarly brutal episode. A so-called *Omega block* had led to a stagnation of the weather pattern, creating a high-pressure ridge that lasted for several days, mainly in France, Italy and Switzerland. The resulting record temperatures caused an excess of deaths that is estimated to range from 35,000 to 55,000[2]. The large majority of the victims

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[2] In a 2008 published article, Jean-Marie Robine and his colleagues even estimated that « Death toll exceeded 70,000 in Europe during the summer of 2003 ».

were elderly living in urban agglomerations (Sardon 2006, 292; Kovatz and Jendritzky 2006; Grize et al. 2005). This led to the implementation of new heat warning systems. However, a second heat wave hit Europe in 2006, which covered a larger area of the Northern Hemisphere and was concentrated in July. The anomalies in maximum temperature also were higher, leading to the hottest summer ever recorded in Switzerland (Rebetez et al. 2008).

Those experiences have been traumatic from both, a psychosocial and a political point of view, and heat wave has since become an issue of general concern about the future of our societies. Global warming appears as a main challenge for human settlement. The trend in warming in Switzerland was twice as pronounced that worldwide during the 20th Century. The process has particularly accelerated during the last 40 years with an average increase in temperature of 0.6 degree Celsius per decade against 0.1 over the past Century. The challenges for human health are particularly intensified by the changing pattern of warming, which is increasingly driven by an increase in maximum rather than minimum temperature and therefore mainly concerns summer rather than winter periods when compared to the past (Rebetez et al. 2008). The Swiss population is therefore increasingly exposed to extreme heat events and is expected to be so in the future. Indeed, despite the ongoing debate around climate change, predictions of an intensification of heat wave episodes (in frequency, intensity and duration) appear to be robust (Beniston 2004). Furthermore, all demographic scenarios consistently predict a massive increase of the share of elderly people (Monnier 2006), thus the expectation of a growing number of frail people who can be considered vulnerable to the effects of climate change.

In this context, many teams are elaborating projections combining demographic perspectives and climate change models. For example, Peng et al. (2011) estimate the yearly excess of deaths for the city of Chicago for 2081-2100 in seven global climate models. Ouranos (http://ww.www.ouranos.ca/) does the same for Canada. The counter-view of these catastrophic scenarios for our future is firstly, that humanity will progressively learn how to cope with climate change and secondly, that the decrease of winter deaths will compensate the rise of summer mortality. The European project Climate Trap, supported by of COST Action 730 since 2005, has the ambitions to construct a Universal Thermal Climate Index including the human capacities for anticipation and acclimatization.

Those studies and the debate about our uncertain future provide a typical illustration of the ‘risk society’ that Ulrich Beck defined as ‘a systematic way of dealing with hazards and insecurities induced and introduced by modernization itself’ (1992, 21). We consider however that those attempts to predict what will happen in the next decades are premature, and that we still need to go back to the basis! Indeed, many crucial knots in the causal chain remain unclear. This paper is a very firs step within a project that focuses on the effects of heat peaks on the mortality rate among the elderly in Switzerland and proposes a perspective on individual and social vulnerabilities that we think to be highly context-dependent. While more and more projections of the future have been established, while a lot of excellent studies have been conducted on the effects of heat waves on human health and mortality, we still argue that several causal links between elderly mortality and heat waves remain unclear and that some crucial hypotheses are still understudied, mainly - and paradoxically - hypotheses related to the environment.

The adverse effect of heat on mortality has been confirmed for different countries located at different latitudes on different continents (Basu 2009; Basu and Samet 2002). However, the literature shows considerable geographic heterogeneity in terms of mortality responses to locally significant increases in temperature. Differences in heat-related mortality across 50 US cities are only partly explained by local climatology, population density and technological adaptation (Medina-Ramon and Schwartz 2007). The mortality response greatly differed between locations with identical weather patterns (Curriero et al. 2002). Geographic gradient are also inversed from one continent to the other. A negative correlation between the optimal temperature for the survival of local populations and the geographic latitude was observed in both the US and Europe. However, the mortality responses to increasing temperatures were stronger in the Northern cities when compared with Southern ones in the US (Curriero et al. 2002), whereas the inverse was observed in Europe (Baccini et al. 2008). The literature also documents a considerable intra-city variability of heat effects on mortality across neighbourhoods and Census tracts, pointing to the relevance of social and community level risk factors (Yardley et al. 2011).

This geographic heterogeneity in heat-related mortality mirrors the complexity of the phenomenon. Heat-related mortality is determined by the vulnerability of a complex socio-ecological system which is composed of 1) physical exposure to high temperature (i.e. heat), 2) the population’s sensibility or its capacity to absorb the heat impact, and 3) the populations’ adaptation to extreme heat events at the societal and individual level (Wilhelmi and Hayden 2010). Physical exposure is probably the best documented factor. Not only temperature per se matters, but also the seasonality, duration and intensity of heat waves are determinant for mortality (Basu and Samet 2002; Anderson and Bell 2011; Rey et al. 2007; Tan et al. 2007). Heat waves occurring earlier in the summer period are associated with more excess-deaths because the exposed populations are not yet acclimatized to high temperatures. Mortality also increases with duration and accumulation of heat during heat waves. Well-functioning warning systems, general awareness and systems for the prevention ensure the population's adaptation and have been found to mediate the negative effects of heat on mortality, as confirmed in France (Fouillet et al. 2008).

However, the second dimension of the vulnerability system, determined by social and environmental susceptibility to heat impacts, is understudied (Aström et al. 2011). The high geographic variability of heat-related mortality may be due to local differences in both the population’s composition in terms of individual risk factors and the socioeconomic and environmental living contexts. This heterogeneity of the exposed population and its environment is seldomly controlled for and therefore may bias comparisons of heat-related mortality between cities or across time.

Earlier research in Switzerland estimated an excess of 975 deaths (7%) during the 2003 heat wave – provided that the relationship between daily temperature and death counts observed during the previous decade prevailed. This excess mortality was much lower than in other European countries (Grize et al. 2005). In the most Southern canton of Switzerland with the highest temperatures (Ticino), death rates were not significantly higher during the heat wave, except to a limited extent among the elderly (Cerutti et al. 2006). However, intra-urban differences in the number of excess deaths due to heat have been noted (Grize et al. 2005) and Switzerland indeed experienced a recent intra-urban differentiation in mortality, especially in the largest or most recently sprawling cities. If mortality was higher in rural than urban regions in the past, a non-linear gradient has emerged since 1980 with higher mortality in city centres and non-urban areas when compared to the agglomeration belts (Lerch et al. 2011).

In this study, we investigate whether differential exposure to heat stress contributes to this new intra-urban gradient in mortality among the elderly population. We model the effect of heat on mortality of the exhaustive Swiss population aged 65 to 89 in a multilevel perspective to contribute to the limited understanding of individual, contextual and environmental susceptibility factors to heat-related mortality.

Diversity in the population's susceptibility to heat-related mortality

The population's exposure to heat-related mortality may differ from one location to the other for at least three reasons. First, individual determinants of susceptibility and adaptation to heat are not distributed uniformly in space. Structural (or compositional) effects may therefore confound the comparison of heat-related mortality between neighbourhoods, cities or countries. Second, the spatial aggregation of individuals and their interactions, as well as exogenous influences, determine location-specific group properties. Those are found to affect the health of all inhabitants (Macintyre et al. 2002). These contextual effects have been shown to influence mortality independently from individual risk factors (Pickett and Pearl 2001). A low level of local material resources, poor infrastructural endowment and limited social cohesion may further influence heat-related mortality. Third, unlike contextual characteristics, local environmental characteristics are specific factors of mortality during heat (Smoyer 1998). Depending on latitude and local climate, humidity-saturated air limits the effectiveness of the body's action to increase thermal comfort through evaporative skin cooling (Kalkstein and Valimont 1986). Air pollution has also been shown to exacerbate heat, although it does only account for a small share of heat-related excess-mortality (Basu 2009).

The most vulnerable populations to heat-related mortality are usually the elderly as well as those with pre-existent diseases (Basu 2009; Basu and Samet 2002). The body's ability to cool down – such as through evaporative skin cooling, increased blood flow to the head, etc. – reduces with age, illness and specific medicine intake. Older and sick people may also perceive heat to a lesser extent and may be constrained in the adoption of adaptive behaviour such as extensive hydration (Hansen et al. 2011). However, except for these biological and medical factors of vulnerability, there is little agreement on individual vulnerability profiles. Social isolation is for sure a risk factor, especially among the elderly, as it prevents people in need to be assisted during heat-related stress (Klinenberg 2002). A low socioeconomic status is also prone to increase risks because of the limited capacity to afford technological adaptations to heat (such as acclimatization) and more vulnerable housing and location (Vandentorren et al. 2006).

Few studies were able to control socioeconomic factors at the individual level or, if they did so, only for a small sample of population or deaths. Due to data constraints, socioeconomic characteristics of the whole population living in a specific place are often used as a proxy for status of all the inhabitants. Since this approach reduces the concept of contextual effects to the aggregation of individual effects, it implies an ecological bias. This may be one reason for the heterogeneity in conclusions of studies that investigated the effect of socioeconomic status at the aggregate level using local percentages of unemployed or low skilled population, median incomes or other composite indexes. No effect on heat-related mortality was observed in Rome (Schifano et al. 2009), Brisbane (Yu et al. 2010), Budapest and London (Ishigami et al. 2008). However, poorer neighbourhoods had a higher excess mortality relative to affluent ones during heat-waves in St. Louis (Smoyer 1998) and median neighbourhood income was associated to higher heat-related mortality among the non-elderly in Milano (Ishigami et al. 2008). Excess mortality was also higher in deprived areas of the city of Paris and its strongly urbanised suburbs (Rey et al. 2009). Comparing 11 US cities, Curriero (2002) also found a stronger mortality response to heat where the level of schooling was lower and poverty more prevalent.

Canoui-Poitrine et al. (2006) observed a change in both the geographical and the socioeconomic composition of the deaths during the heat wave in Paris when compared to reference years. They therefore concluded that contextual and individual factors both matter for heat-related mortality. But in Sao Paulo, regional levels of unemployment had no significant impact (Gouveia et al. 2003), whereas the lower-skilled population indeed had a higher excess mortality. This contrasted with the findings in Mexico and Chile, where individual educational attainment did not have an effect (Bell et al. 2008). However, manual workers in France had a higher mortality than managers at older ages during heat waves (Vandentorren et al. 2006).

Even when the effect of socioeconomic status is estimated simultaneously at the individual and contextual level, results diverged. Unemployment levels did not affect heat-related mortality in Barcelona, but the lowest skilled elderly women were characterized by the highest excess mortality (Borell et al. 2006).By contrast, Browning et al. (2006) showed that individual socioeconomic characteristics had the same effect on mortality during the 1995 heat wave in Chicago when compared to previous summers. But neighbourhood affluence and commercial vitality protected individuals only during the heat wave. A more dynamic social ecology, it was argued, is protective against heat related mortality since it maintains healthier social institutions and limits the decay of infrastructure in neighbourhoods.

Conclusions regarding social risk factors are heterogeneous as well. Social isolation at the individual level is often implied from marital status, assuming the single, divorced and widowed to be more at risk of isolation. Unmarried elderly had indeed a higher mortality in Rome (Schifano et al. 2009) and in Paris (Canoui-Poitrine et al. 2006). In the latter however, this may have resulted from a mortality selection effect, as marital status did not play a role when controlling for several individual and household-level variables indicating social status (Vandentorren et al. 2006). Rather than marital status, living arrangement may specifically matter. In Modena, unmarried women did not have a higher mortality when controlling for negative effects associated to living in either a single-person household or a care institution (where people are probably frailer and accumulate co-morbidities). At the local level, a denser social interaction is usually expected to increase assistance to those people most sensible to heat. Assuming the demographically more stable neighbourhoods to be characterized by a higher degree of social interaction, Smoyer (1998) and Uejio et al. (2011) indeed observed a negative relationship with heat-related mortality in St. Louis and in Philadelphia. The empirical sociological investigation of Klinenberg (2002) on the 1995 episode in Chicago showed higher vulnerability among African-Americans compared to Hispanics. The author attributed this difference to the fact that many African-Americans lived in areas of sub-standard housing and less cohesive neighbourhoods while Hispanics lived in areas of higher density but with more social cohesion. However, Browning et al. (2006) did not find an effect of the neighbourhood's demographic stability.

In contrast to the challenging conclusions on socioeconomic differentials of heat-related mortality at the individual and contextual level, there is more convergence of studies with results regarding the impact of environmental factors. The density of the urban environment is a major determinant. Dark built environments absorb more heat than green areas, cool down to a lesser extent at night and the nearby and high-rise buildings lower wind speed that may refresh urban air. Moreover, the concentration of human activity exacerbates meteorological phenomena through pollution and the wasting of heat due to the excessive use of energy. The combinations of those factors have been explored by epidemiologists and environmentalists who coined the term *urban heat island* (UHI) about half a century ago.

Indeed, more densely settled US cities (or neighbourhoods within cities) were associated with higher heat-related mortality (Uejio et al. 2011; Medina-Ramon and Schwartz 2007). The urban morphology matters as well. In summer 2003 urban centres and suburban places in Switzerland showed indeed similar patterns of heat related mortality, while rural places were spared (Grize et al. 2005). Urban sprawl particularly increases the urban heat island effect because the built environment extends geographically. More sprawling US metropolitan regions experienced a stronger increase in heat events during the second half of the 20th Century (Stone et al. 2010). In China, heat island effects were associated to more numerous and more intense heat waves, as well as with a higher excess mortality, in central and suburban communes (Tan et al. 2010).

This review of the literature shows many apparent contradictions and highlights that living environments are made up of a combination of many factors, which create 'sub-environments'. Their exposure to the risk of heat-related mortality has to be assessed to better target prevention. Accumulation of disadvantages has particularly to be taken into account since individual, contextual and environmental factors of heat-related mortality tend to overlap in highly differentiated urban environments. More densely populated neighbourhoods may be inhabited by poorer subpopulations and this fiscal disadvantage in turn may alter the development and maintenance of local infrastructure. In the US, city-centres clearly accumulate vulnerability factors of heat-related mortality (Reid et al. 2009). Indeed, the independent impact of population density on heat-related mortality was small or in the unexpected direction when controlling for socioeconomic characteristics of places, such as in St. Louis, Massachusetts and Paris (Rey et al. 2009; Smoyer 1998; David Hattis et al. 2012).

Hypotheses

The importance of simultaneously considering various confounding risk factors of heat-related mortality that operate at different social levels has often been underlined (Basu and Samet 2002; Yardley et al. 2011; Smoyer 1998; Canoui-Poitrine et al. 2006), but has rarely been operationalized (see Browning et al. 2006 for one of the exceptions). While relying on cohort-follow up data of the exhaustive Swiss population, we contribute to this line of multilevel research. First, the independent effect of heat on mortality is estimated after controlling for other individual, contextual and environmental risk factors. Second, we investigate - through the specification of interaction effects - whether heat exacerbates or attenuates individual and contextual differentials of mortality. Interactions between heat and the urban environment are investigated as well.

We expect older people to be more vulnerable to heat stress, especially those who are more frail or those with pre-existing diseases. Socioeconomic status and social isolation at the individual level is well approached by educational attainment and marital status, respectively, because these variables are most clearly related to health status in Switzerland (Burton-Jeangros 2009) and strongly affect survival. At age 30, men and women holding a tertiary school diploma can expect to live respectively up to 7.1 and 3.6 years longer than the lowest skilled, and married people benefit from a similar advantage compared to singles (Spoerri et al. 2006; Schumacher and Vilpert 2011). We expect heat to exacerbate these socioeconomic inequalities of mortality.

The socioeconomic status of the living context may increase mortality through physiological effects on health due to poor material resources and infrastructural endowment. The local distribution of living conditions matters, too. Psychosocial stress experienced in the course of local social comparison in highly stratified populations may motivate risky health behaviours (Wilkinson 1996). Wilkinson (1996) and Kawachi et al. (1997) also argued that the negative effect of inequality on mortality is indirect through the local corrosion of social capital. Living in more unequal places with lower social interaction may particularly increase mortality during heat, as social capital is determinant for the promotion of adaptive behaviour among those elderly who are restricted in their mobility and perceive heat to a lesser extent.

At the environmental level, larger parts of the living context covered by green and natural areas should be particularly beneficial to survival during heat as they must attenuate the heat island effect. Additionally, a lower population density of the built environment should limit excessive energy consumption and therefore not exacerbate heat. We also anticipate individuals living on the top floors of apartment-buildings to be particularly exposed to heat stress and the related risk of dying (Vandentorren et al. 2006).

Data and method

Using multilevel survival analysis, we estimate heat effects on mortality adjusted for the local and temporal clustering of the individuals' heat exposure. Socioeconomic differentials in the susceptibility to heat and the relevance of contextual and environmental risk factors are also investigated.

Physical exposure to heat is measured in relying on time-series data of daily temperature maxima during the main summer months (June, July and August) for the years 2001 to 2006. Meteorological data were measured in the 20 stations of MeteoSuisse located in an urban agglomeration of Switzerland (with population size of more than 45'000 inhabitants). This time-varying information on physical exposure to heat in each of the measurement communes is imputed to the monthly exposure population in the whole urban agglomeration. Thus, heat is measured for the Swiss urban population disaggregated by agglomeration of residence and month of exposure. The mortality effect of different indicators of the monthly intensity of heat have been tested, including the third quartile and 95th percentile of daily temperature maxima and cumulative temperature above different thresholds. All of these indicators show the same effect on mortality, but the monthly cumulative maxima temperature above a threshold of 34 degrees had the most significant effect and provided the best fit of the model to the mortality data. This threshold was also suggested for Switzerland by Grize et al. (2005) and is subsequently used in this analysis.

The monthly exposure population aged 65 to 89 is estimated for the summer months 2001 to 2006 from the *Swiss National Cohort* database: 94% of registered deaths for the years 2001-2008 have been linked to individuals enumerated at the 2000 Census using a mix of deterministic and probabilistic methods (Bopp et al. 2008). Unlinked deaths were imputed according to a stratified random technique in a later version of the SNC database and are included in our analysis. Exposure to mortality starts in June of each year and ends either with death or the truncation due to emigration (which is known only for foreigners) or the end of the summer period (end of August). The dependent mortality is total mortality.

Multilevel models are specified to adjust the standard errors of the heat effect and other contextual effects for the dependence between observations: individuals constitute the first analytical level and are indeed clustered at two hierarchical levels. First, they live in a local living context. To ensure reliable estimates based on sufficient number of events for each category of analysis, the official Swiss communes have been regrouped within each agglomeration according a functional urban classification based on the continuity of the built-up area, density, demographic growth, commuting and economic structure (Schuler et al. 2005). Communes are regrouped here in three groups: city centres; suburban municipalities which constitute the first agglomeration belt; and periurban or high-income municipalities as the second more recent belt. Second, the populations of each living context are nested temporarily and spatially in, respectively, months of exposure and agglomerations for which the measures of heat are available.

Discrete-time logistic regressions are specified in allowing the intercept to vary across agglomerations and months, and local living contexts (Rasbash et al. 2005). The logged-odds of dying are estimated from the model intercept – which constitutes the baseline hazard function of mortality all over Switzerland according to time-varying age ($\beta_0(t)$) – and the additive effects of individual and contextual variables, as well as the effect of heat (respectively x_{1ijk}, W_{1jk}, and $Heat_{1k}$):

$$\log\left(\frac{h_{ijk}(t)}{1-h_{ijk}(t)}\right)=\beta_0(t)+\beta_1 x_{1ijk}+\alpha_1 W_{1jk}+\alpha_2 Heat_{2k}+(v_{0k}+u_{0jk}+e_{0ij}),$$ with individuals i nested in 57 local living context j, nested in 38 exposure months for each of the 20 agglomerations k.

The variance in mortality is partitioned into variation between individuals within each cluster (corresponding to e_{0ij}) and variation in average mortality between clusters (u_{0jk}, v_{0k},). Models are estimated in MLwiN version 2.2 through the Markov chain Monte Carlo method (MCMC; Rabash et al. 2005; Browne 2003)[3].

The models control for individual mortality differentials according to *age, sex, marital status* (unmarried versus married) and the level of *educational attainment* (using broad ISCED categories; none to compulsory Secondary School I, Secondary School II which is either on-the-job training or general school, and Tertiary). *Frailty and the presence of co-morbidities* is approached by residence in an elderly or health care institution.

Relative differences in *material deprivation* between living contexts are estimated using the Townsend index (Townsend et al. 1988); an un-weighted sum of standardised percentages of overcrowded private households (i.e. more than one person per room), non-owned private dwellings, unemployment rates and the share of population aged 25 and higher having at best a Secondary School I diploma. Based on the relative importance of deprived subpopulations in each cluster, relative to the Swiss average, area-level deprivation is inferred: a high value of

[3] The relevance of structural and contextual factors for the geography of mortality in Switzerland is evaluated against the step-wise decrease in inter-cluster variances, while the statistical significance of each factor in the explanation of individual mortality differentials is evaluated against the step-wise improvement in the statistical fit of the model to the empirical data, which is assessed by the Bayesian Information Criterion (BIC).

the index means a higher than average level of deprivation. *Material inequality* within the local living context is estimated using an unconventional Gini-index based on the distribution of wealth, approximated here for each individual by an un-weighted sum of the inverse attributes used for the Townsend index[4]. The higher the Gini-index, the more unequal wealth is distributed among inhabitants of a living context.

The Swiss land-use statistics of the Federal Statistical Office (OFS) are used to characterize urban environment. In this analysis, we rely on the version 1992/97 because the last version had yet to be updated for all Swiss communes. The built environment is distinguished from green and recreational areas which include surroundings of houses and blocks (which are assumed to be mainly green areas), woods, water points, public parks, etc. Population density is estimated for relevant built areas rather than for the total surface of areas.

Results

The likelihood of dying sharply increased with age and was lower for women (see Table 1). Results are also congruent with what we already know about socioeconomic differentials in mortality. The protective effects of marriage and a higher level of education were confirmed. Mortality of individuals living on the top floors of apartment-buildings did not significantly differ when compared to residence in other private dwellings. However, the much higher likelihood of dying for residents in elderly or health care institutions confirms their high level of frailty (Lalive d'Epinay & Spini, 2008). As expected, a higher level of local material deprivation was associated with a higher mortality, although this effect was mediated by local inequality which interestingly decreased the likelihood of dying. Collective resources which benefit all residents may be more developed thanks to important fiscal contributions of a small minority of very affluent inhabitants, as observed in London (Stafford and Marmot 2003). Environmental amenities such as the local availability of parks or other green and natural areas only had a slight protective effect on mortality. After controling for individual determinants, residents of more densely populated built-up areas had a slightly lower mortality.

Table 1

Cumulative heat during the month of exposure significantly increased mortality, but this positive effect was small. Residents of elderly-homes or health care institutions were more affected than those living in private dwellings. The effect of heat did not significantly differ according to age, sex and marital status. In fact, heat attenuated socioeconomic gradients of mortality at both the individual and contextual level. The higher skilled population facing generally lower mortality was significantly less protected during hot months. Also, the negative effects on mortality of local material deprivation, as well as the positive effects of collective resources in more unequal contexts, seemed to be attenuated during hot months – although these interactions with contextual characteristics were not statistically significant.

[4] i.e. the sum of dummy variables indicating: not living in an overcrowded household, ownership of the dwelling, not being unemployed and having an educational attainment above the compulsory Secondary I level.

Environmental characteristics mediated the impact of heat on mortality as expected – although not significantly. The share of green and natural areas tended to be associated with a lower mortality during hot months, while a denser built-up environment seemed to exacerbate the effect of heat on mortality.

Discussion and conclusion

The Swiss population is increasingly exposed to heat-related stress in summer periods. We have investigated the independent effect of heat as well as its interactions with other determinants of mortality operating at different levels of society. The aim was to simultaneously analyse the diverse and confounding effects on heat-related mortality of the socio-ecological systems of vulnerability in Swiss urban agglomerations. This was made possible by the integration of meteorological information, mortality data linked to the Census-enumerated elderly population and land use statistics. The spatial and temporal clustering of the elderly heat exposure was controlled for in a multilevel mortality model. It was assumed that heat not only generally increased mortality, but also exacerbates individual and contextual differentials of mortality due to the unequal opportunities to adapt individual behaviour to heat. The role of environmental characteristics in increasing physical exposure to heat and thus in aggravating its effect on mortality was investigated, as well.

The independent effect of heat on monthly mortality in Switzerland turned out to be very small. This confirms previous conclusions from studies conducted at the ecological level (Grize et al. 2005; Cerruti et al 2006). Nevertheless, our results identified specific subpopulations which were more susceptible to the heat impact. As indicated by the increased risk of dying in institutions during hot summer months, frailty and the prevalence of pre-existing diseases among the elderly appeared more important for heat-related mortality when compared to biological age which did not significantly matter. However, heat attenuates rather than exacerbates socioeconomic differentials of mortality in Switzerland. This may indicate a high minimum standard of housing conditions in Switzerland and/or efficient interventions of the socio-sanitary system among the socioeconomically most vulnerable. We can also speculate about the impact of mortality compression in old age which in Switzerland reached one of the highest levels ever observed. Mortality is massively concentrated between 72 and 88 years of age for men, 78 and 92 for females. In other words, there is little room for mortality differentials. In another study, we observed a relative (and statistically significant) over-mortality of the immigrants and persons with a low educational level until 80 for males, 85 for females, followed however by an inversion of this pattern among the oldest old. Selection process may be the cause of this change (Oris and Lerch 2009). In this context, heat waves may have only a limited harvesting effect. These speculations require further research.

When controlling for individual factors of mortality, contextual effects do not play a statistically significant role on the impact of heat on elderly mortality in Switzerland. As for individual differentials, contextual differentials in mortality tended to be attenuated during heat. Contextual resources may come too late for being efficient during heat stress, which usually appears suddenly and lasts for only a short period. Moreover, the results underline the necessity to measure socioeconomic differentials in heat-related mortality at the individual rather than the aggregate level. Environmental amenities that were often advanced to mediate the effect of heat on mortality, did also not play a significant role in Switzerland. Population density of the built environments tended to exacerbate the effect of heat, whereas environmental amenities tended to attenuate it. In conclusion, this analysis mainly emphasises the protective role of behavioural adaptation at the individual level.

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Table 1: Multilevel model of monthly mortality, Swiss population aged 65-89 during the summer months June, July and August of 2001 to 2006.

		OR	sig	OR	sig	OR	sig
Constant		-5.365		-5.365		-5.382	
Individual risk factors							
Age							
65-74		0.312	*	0.312	*	0.313	*
75-89 (ref)		1		1		1	
Sex							
Male (ref)		1		1		1	
Female		0.503	*	0.503	*	0.504	*
Marital status							
Married (ref)		1		1		1	
Not married		1.452	*	1.450	*	1.446	*
Educational level							
Sec I		1.151	*	1.149	*	1.147	*
Sec II (ref)		1		1		1	
Tertairy		0.809	*	0.811	*	0.811	*
Dwelling type							
Other (ref)		1		1		1	
Penthouse appartement		0.997		1.000		0.999	
Elderly or heat care institution		3.360	*	3.370	*	3.377	*
Contextual and environmental risk factors							
Monthly cumulative heat over 34C				1.010	*	**1.007**	*
& interaction with:	age 65-74					0.995	
Sex	Female					1.001	
Marital status	Not married					0.996	
Education	Sec I					1.002	
	Tertairy					**1.009**	*****
Dwelling	Penthouse appartement					0.999	
	Elderly or health care institution					1.017	*
Material deprivation						1.017	*
Intra-regional inequality						0.978	*
Cumulative heat &	Material deprivation					0.9997	
	Intra-regional inequality					1.0007	
Pct green and natural areas						0.9978	*
Cumulative heat &	Pct green and natural areas					0.9999	
Density of built environment						0.9994	*
Cumulative heat &	Density of built environment					1.00001	
N person-months		11431250		11431250		11431250	
N deaths		29877		29877		29877	
DIC		125583		125565		125531	

Source: Swiss National Cohort, MeteoSuisse and Swiss Land Use statistics. * = statistically significant at 0.05 level.