Who should heat prevention plans target? A heat susceptibility indicator in the elderly developed based on administrative data from a cohort study

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Abstract

Background: A heat susceptibility indicator based on current information systems was developed in order to identify elderly subjects at increased risk of dying during heat-wave days compared to non-heat-wave days.

Methods: Susceptibility was measured as the relative difference between the predicted probabilities of dying during heat-wave days and non-heat-wave days, estimated through a Poisson generalized linear model. The study analyzed a cohort of residents in Rome aged 65+ between 2005 and 2007 and examined the following factors: age, gender, marital status, socioeconomic position, and clinical conditions.

Results: A total of 624,561 subjects were analyzed. The indicator performed well for the 65–74 age group, but not for the 75+ age group, for whom we computed an alternative index based on the absolute difference rather than the relative difference between the predicted probabilities. Moreover, the indicator revealed that 65–74 year-old subjects displaying the highest susceptibility (top 5%) to death during heat waves had at least one of the selected chronic pathologies, and 90% of them had chronic obstructive pulmonary disease. Additionally, 60% of those with the highest susceptibility among 75+ year olds had at least three chronic diseases, 80% were women, and 90% were not married.

Conclusions: The susceptibility indicator currently used in Rome is a valid and significant tool for selecting at-risk elderly subjects who can benefit from heat prevention programs. Also, this heat susceptibility indicator, which is based on administrative data only, does not require additional cost for implementation and could be easily adapted to other populations.

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Introduction

Extreme temperatures and heat waves are a serious threat to human health, especially for people living in urban areas. In the literature, there is evidence that high temperatures differentially affect population subgroups according to their physiological and behavioral responses to heat, which depend on clinical, social, and demographic factors [1-4]. Overall, the elderly experience the most deaths and worsening of pre-existing chronic conditions due to heat waves [1]. Therefore, reducing mortality and

morbidity faced by the elderly is an important aim for public health, which partially overlaps with the more general issue of frailty among the elderly [5]. Indeed, frail subjects are more vulnerable to environmental hazards, such as extreme temperature events, because of their reduced behavioral and physiological resources for adaptation [6]. Case-finding algorithms based on administrative data have been developed for screening frail persons in the community and used for various objectives and target populations [7-9]. However, not all frail individuals have a higher susceptibility to heat, and a portion of less frail individuals might actually be more susceptible to high temperatures. In the field of heat prevention, it is critical to protect elderly individuals from adverse health outcomes that could result in hospital admission or death, and this can be achieved through prevention and active surveillance [10]. However, no specific algorithm has been developed to identify elderly individuals that are susceptible to the negative effects of extreme temperatures.

In Italy, since 2004, a national program has been operational for the prevention of heat-health effects based on city-specific Heat Health Watch Warning Systems (HHWWS). This program includes local response plans that are specifically focused on susceptible subjects, as recommended by Italian prevention guidelines [11]. Prevention measures aim to reduce the impact of heat on health, especially in these subgroups, with the ultimate goal of maximizing limited economic health care resources. In Rome, the primary component of the local prevention program is the active surveillance of high-risk elders (65+ years) by general practitioners (GPs) [12]. However, reaching the most susceptible subgroups has been one of the challenges faced by this prevention program. The objective of this study was to develop a heat susceptibility indicator based on administrative data in order to identify high-risk elderly subjects during heat waves. This indicator is currently used by the local program in Rome as a tool for identifying at-risk individuals in order to appropriately target prevention activities.

Materials and Methods

To develop the indicator, we used a definition of susceptibility that was based on the increased probability of dying during heat-wave days vs. non-heat-wave days estimated at the individual level.

Therefore, the higher the difference was between the two probabilities, the higher the level of susceptibility to heat.

Two approaches were tested in order to measure heat susceptibility. The absolute score (AS) and the relative score (RS) were calculated to determine the probabilities of dying on a heat-wave day and a non-heat-wave day.

$$\text{Absolute Score} = P_H(y_i) - P_{NH}(y_i)$$

$$\text{Relative Score} = \frac{P_H(y_i) - P_{NH}(y_i)}{P_{NH}(y_i)}$$

where $P_H(y_i)$ is the probability of dying on a heat-wave day for subject i, and $P_{NH}(y_i)$ is the probability of dying on a non-heat-wave day for subject i.

The relative effect is often a clearer indicator of the strength of an association [13]. It is preferable because it is less affected by the mortality rate. In fact, each individual increment of risk is defined in relation to its baseline value. Therefore, the advantage of this measure is that it allows comparisons to be made among subjects with differing baseline risks of dying, which is highly correlated with age. However, the limitation of this technique is that it may not be variable enough among subjects. Thus, the absolute score, which allows more variation, was also considered in cases when the RS did not perform adequately.

The probability of dying during heat-wave days and non-heat-wave days was estimated through a predictive model built on a three-year cohort of residents in Rome, including information on subject's risk factors as effect modifiers. These included age, gender, marital status, census tract area-based socioeconomic position [14], the presence/absence of specific pathologies, and the number of hospital stays within the previous two years for causes other than those selected (Table 1) [1,15-17]. We estimated the probability for every combination of the modalities of the covariates included in the model.

The subjects were 65 years or older and were enrolled during the summer months (May 15 to September 15) in 2005–2007. A follow-up of the cohort was carried out to ascertain life status every summer during the study period, and death status was retrieved from the Regional Registry of Causes of Death.

Table 1. Risk factors included in the analysis

Risk factors						
Demographic	Social	Clinical				Clinical severity
		Cardio/cerebrovascular diseases	Pulmonary diseases	Psychiatric and central nervous system diseases	Other diseases	Number of HDD for selected causes
Age	**Marital Status**	HDD (ICD9)				
65-74	Married	Ischemic heart disease	Chronic pulmonary disease	Psychiatric disorder	Malignant neoplasm	0
75-84	Not married, widowed, divorced	(410-414)	(490-496)	(290-299; 300.4; 301.1; 309.0; 309.1; 311)	(140-208)	1
85-94		Conduction disorder		Other CNS disorders	Diabetes mellitus	2
95+	**SES**	(426)		(330-349)	(250)	3
	Medium/High	Cardiac dysrhythmia			Acute or chronic liver disease	4+
Gender	Low	(427)			(570-572)	3+
Female	Missing	Heart failure (428)			Renal failure (584-588)	**Number of HDD for any other causes**
Male						0-1
		Other cardiovascular diseases (390-429 except 410-414; 426;427;428)				2-3
		Cerebrovascular disease (430-438)				4+

HDD: Hospitalization Diagnosed Disease; SES: socioeconomic status; CNS: Central nervous system

We only considered deaths for natural causes (International Classification of Diseases, 9th Revision [ICD-9]: 1–799) occurring between May 15 and September 15 of each year. The cohort was already defined in a previous study aimed at estimating the effect of heat waves in different elderly subgroups that considered the same set of predictors for mortality used in the aforementioned study [3].

Demographic data were derived from the Population Registry of the Rome Municipal Office, whereas information regarding health status was extracted from regional hospital discharge files (Regional Hospital Information System). Also, a subject was defined as suffering from a pathology if he/she had experienced at least one hospital stay related to a specific cause within the previous two years.

Heat-wave days were defined as those days with maximum apparent temperatures [18] above the monthly threshold for two or more consecutive days; we used the threshold values defined by the Italian warning system (i.e., May: 28.5°C, June: 32.5°C; July: 33.5°C; and August/September: 34.5°C) [11]. To account for the possibility of delayed effects of heat-waves on mortality, the three days following heat episodes were also included in the heat-wave definition.

All covariates, as well as their interactions with a dummy variable indicating the presence/absence of a heat wave, were initially included in a Poisson regression equation. The final model included all variables that displayed a significant interaction with the heat-wave indicator. In order to increase the power of the interaction tests, a p-value cut off of 0.20 was used for type I error [19].

Separate models were run for each of the subgroups (65–74 and 75+ age groups) because age is known to be an important factor modifying the association between temperature and mortality. Results of the models were then used to compute the susceptibility indicator for each age group.

The score had as many different values as the number of combinations of modalities of the covariates analyzed in the studied population. Some combinations of modalities might be associated to very similar score values (i.e., males, with no pathologies, in the age class 75-84 yrs might have a similar score values as males, with no pathologies, in the age class 85-94 yrs). We tried to classify the

population into classes on the basis of increasing score values using percentiles (i.e., deciles). However the number of possible classes depends on the concentration of the score distribution. The first class comprised those with negative scores, (i.e., subjects that were less likely to die during heat-wave days compared to non-heat-wave days), the middle class was comprised of individuals without increased risk (i.e., scores close to zero), and the higher classes included those with a greater risk of dying on heat-wave days.

The indicator was validated by analyzing the mortality of residents from Rome aged 65 years and older during the summers of 2008 and 2009. Each resident was assigned a score based on their individual risk factors as defined by the indicator. The increased risk of dying during heat-wave days compared to non-heat-wave days was computed. It was calculated using both the relative risk and the risk difference because the former is more suited to validate the RS, whereas the latter is more suited to the AS. The predictive capacity of the indicator was evaluated based on the correlation between mortality risk and score values.

Results

Study population

The selected cohort was composed of 624,561 subjects, corresponding to 203,627 person-years of heat-wave exposure (including the three post heat-wave lag days) and 437,520 person-years of non-heat-wave exposure. In the two cohorts (65–74 and 75+ age groups) 4,139 and 14,470 deaths were recorded, respectively. Additionally, previous hospital stay was noted in only 34% of the cohort.

Results of the predictive model

For the 65–74 age group, the final models included interaction terms between the heat-wave indicator and hospital stay for malignant neoplasm, cardiac dysrhythmia, chronic obstructive pulmonary disease, and previous admission for pathologies other than those selected (Table A1, online Additional file). The most important predictive variable was previous hospital stay for chronic pulmonary disease, which increased the relative risk of dying during a heat-wave episode by 15% (data not shown). In contrast, the other variables were associated with a lower risk of dying during heat waves compared to non-heat-wave

periods. For the 75+ age group, predictors incorporated into the final model included being widowed or divorced, unmarried, female, and >85 years old, which were all associated with increased risk during heat waves. Furthermore, previous hospital stay for malignant neoplasm, cardiac dysrhythmia, acute or chronic liver disease, and ischemic heart disease was associated with a risk of <1 for dying on heat-wave days (Table A2, online Additional file).
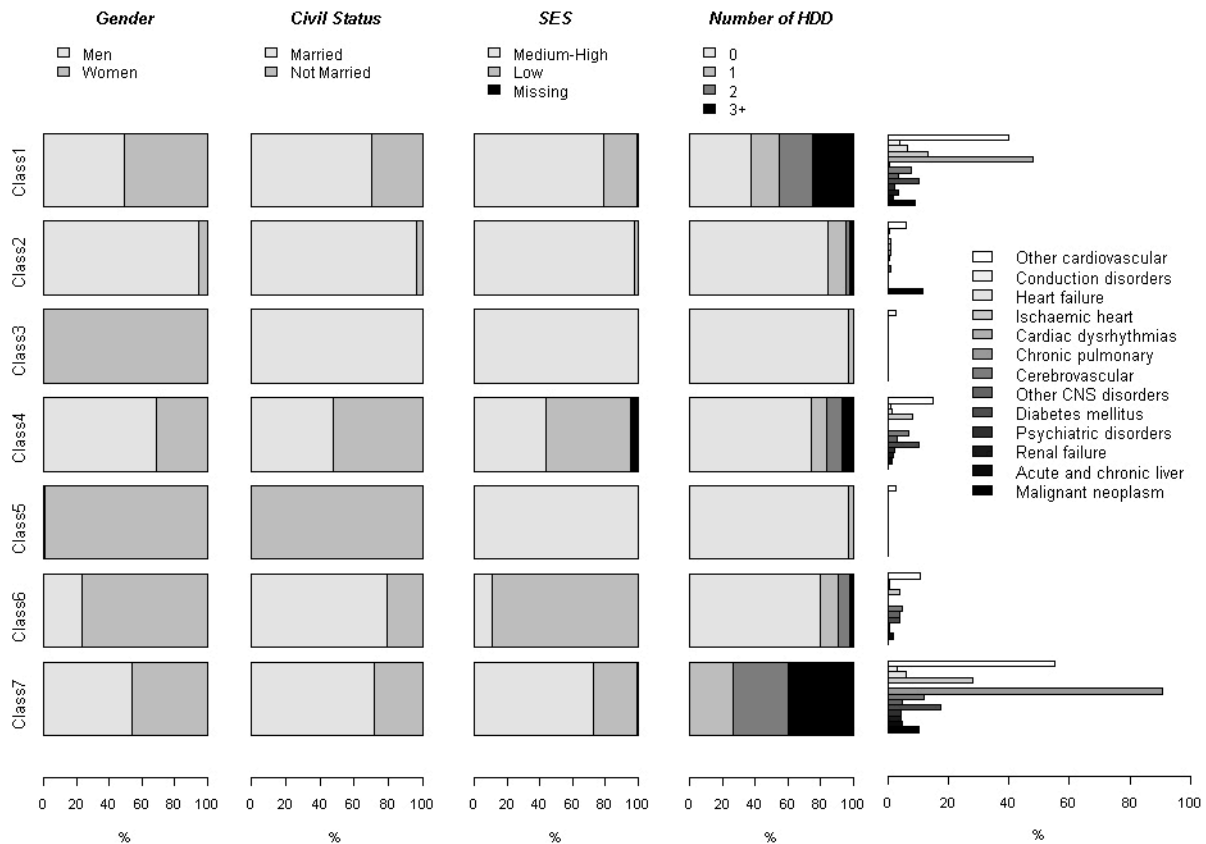
The indicator

For the 65–74 year-old group, the RS score distribution allowed us to properly discriminate the population into classes based on increasing susceptibility. In contrast, for the 75+ age group, the score distribution was too concentrated to allow categorization. Hence, we had to modify the score formula for the 75+ age group, considering the absolute instead of the relative difference between probabilities. The AS allowed us to better discriminate the entire population, and particularly the upper risk classes. Fig. 1 describes the AS and RS score distributions for both age groups, but only for the upper 10th percentile (higher risk). Finally, the best categorization we could obtain resulted in seven classes for the 65–74 age group using RS and ten classes for the 75+ group using AS.
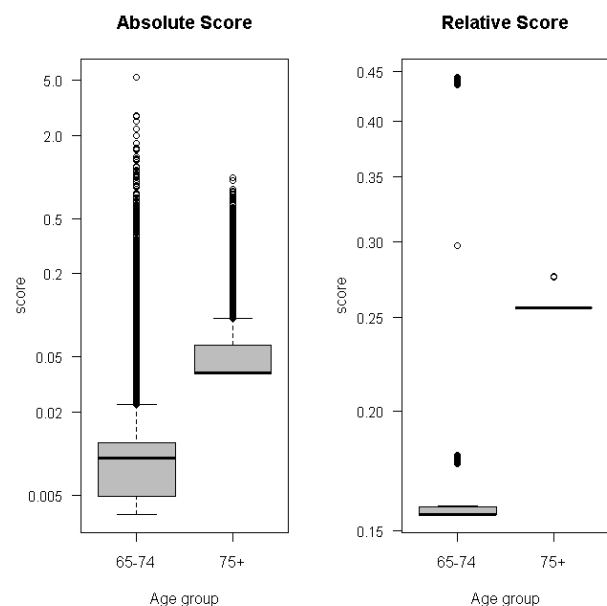
Figure 1. Absolute and relative score distributions over the 90th percentile of the study population

Study population: Rome, 2005–2007

Figure 2. Classes of the susceptibility indicator for the 65–74 age group cohort

SES: socioeconomic status; HDD: Hospitalization Diagnosed Disease; CNS: Central nervous system

Age group 65–74

The higher risk class (class 7) was characterized mostly by chronic obstructive pulmonary disease (COPD) (90% of all subjects included in this class) (Fig. 2). Notably, this subgroup had no hospital stay for causes other from those selected (data not shown). Conversely, only 60% of the population included in the lowest risk class (class 1) had at least one of the selected pathologies, with the majority of cases involving cardiac dysrhythmia. However, in classes 2 to 6 only 25% had a previous hospital stay. Also, we observed that the sociodemographic characteristics did not differ among the classes in this age group (Fig. 2).

Age group 75+

Here, the higher risk class (class 10) was mainly characterized by sociodemographic factors: it was composed mostly of women that were 85 years and over, who lived alone. In contrast, the lower risk class was composed mainly of married men aged 75–84 years. All subjects in class 1 and class 10 had at least one of the selected pathologies, and >50% had at least three pathologies. The most frequent pathologies observed in both classes were "other cardiovascular diseases" (Table 1).

As expected, in class 1 there was a higher prevalence of pathologies associated with a lower relative risk of dying during heat-wave episodes, including ischemic heart disease, cardiac dysrhythmia, malignant neoplasm, and acute or chronic liver disease.

Validation results

The indicators were attributed to more than the 99% of the validation population. "Missing" corresponded to those combinations of categories not represented in the cohort.

Table 2. Relative risk (RR) and rate difference (RD) of dying in the validation population

		65-74 ages (Person yrs=210,822)								
		Relative score (RS)								
		Mortality rate			**95% CI**				**95% CI**	
	Person-years %	**Heat wave**		**RR**			*p-value*	**RD**		
Class		**yes**	**no**		*lower*	*upper*			*lower*	*upper*
1	3.5	7.7	7.0	1.09	0.82	1.45	*0.553*	0.63	-1.48	2.75
2	28.1	4.5	4.4	1.03	0.90	1.17	*0.668*	0.13	-0.45	0.71
3	24.5	0.9	1.1	0.82	0.61	1.11	*0.208*	-0.19	-0.48	0.10
4	19.2	3.5	3.3	1.04	0.87	1.25	*0.635*	0.15	-0.47	0.76
5	15.7	1.5	1.6	0.95	0.70	1.27	*0.711*	-0.09	-0.54	0.37
6	7.2	2.8	1.9	1.50	1.06	2.14	*0.023*	0.95	0.10	1.80
7	1.5	13.7	11.1	1.24	0.89	1.73	*0.206*	2.66	-1.57	6.89
Missing	0.3	20.0	24.9	0.80	0.44	1.47	*0.471*	-4.97	-18.01	8.08

		>74 ages (Person-years=196,276)								
		Absolute Score (AS)								
		Mortality rate			**95% CI**				**95% CI**	
	Person-years %	**Heat wave**		**RR**			*p-value*	**RD**		
Class		**yes**	**no**		*lower*	*upper*			*lower*	*upper*
1	1.2	41.4	38.0	1.09	0.88	1.35	*0.442*	3.36	-5.31	12.03
2	17.5	9.9	8.9	1.12	0.99	1.25	*0.067*	1.03	-0.08	2.14
3	13.7	5.5	5.2	1.07	0.90	1.28	*0.439*	0.37	-0.57	1.31
4	8.9	9.2	9.0	1.02	0.86	1.20	*0.853*	0.14	-1.38	1.66
5	20.6	6.3	5.8	1.09	0.95	1.24	*0.224*	0.50	-0.32	1.33
6	7.9	14.6	11.4	1.27	1.10	1.48	*0.001*	3.13	1.17	5.09
7	10.7	23.9	21.4	1.12	1.02	1.23	*0.022*	2.53	0.34	4.73
8	9.8	22.2	18.7	1.19	1.07	1.32	*0.001*	3.52	1.32	5.71
9	7.2	32.6	27.6	1.18	1.06	1.30	*0.002*	4.93	1.83	8.04
10	1.8	56.4	49.1	1.15	0.99	1.34	*0.076*	7.30	-0.90	15.51
Missing	0.7	67.7	48.5	1.40	1.11	1.76	*0.004*	19.19	5.57	32.82

§ *RR and RD on heat-wave days vs. non-heat-wave days are computed by class of susceptibility indicator in the two age groups*

RS score - age group 65–74

As expected, the higher risk classes (class 6 and 7) presented the highest relative risk for dying on heat-wave days, while increased heat-wave-related mortality was not observed in the other classes (Table 2). Notably, the first and last classes presented the highest mortality rates.

AS score - age group 75+

Increasing values of AS corresponded to greater risk differences of dying on heat-wave days vs. non-heat-wave days, with significant increase in risk from class 6 (Table 2). Also, as observed in the other model, the first and last class of risk had the highest mortality rates.

DISCUSSION

A heat susceptibility indicator was developed based on data from current information systems for identifying subgroups within the elderly population at increased risk of dying during heat waves. This indicator could be used to select those elderly subgroups whose baseline risk of mortality is significantly modified by exposure to extreme heat [1-4,15-17], in order to distinguish them from the wider group of frail elderly individuals [6]. This indicator is readily available for local health authorities to support their preventive programs. Moreover, for implementation, it only requires the availability of administrative data and some statistical skills.

In the elderly, health conditions are the major drivers of individual susceptibility [1-4,15-17]; however, these factors interact with demographic and socioeconomic characteristics relative to both the individual and the community, as well as local adaptation measures [6,20,21]. This combination of effect modifiers of the heat-mortality relationship determines the actual individual risk. Indeed, these factors vary from one population to another, or even within the same population, and can change over time. For this reason, an indicator of susceptibility to heat must be population- and time-specific. Our indicator fulfills these requirements because it is based on the estimated probability of dying on heat-wave days for the specific population on which the indicator was

then to be used. In fact, the indicators developed in the 65–74 and 75+ age groups performed sufficiently well, assigning the highest scores to those with the highest risk of dying during heat waves.

Among the 65–74 year olds, subjects with the highest score were characterized by having had at least one hospital stay for pathologies known to be associated with greater susceptibility to heat, particularly COPD. In the 75+ age group, the indicator revealed that very old women living alone were at higher risk. Additionally, all those in the class at highest risk had had at least one hospital stay for one of the selected pathologies, particularly "other cardiovascular" and cerebrovascular diseases (Fig. 3). However, it should be noted that these pathologies are not only associated with heat susceptibility, but are typical of a population with a higher general risk of mortality.

Notably, the pathologies contributing to the indicator (i.e., significant predictors in the model) for the 75+ age group (i.e., chronic and acute liver disease, dysrhythmia, ischemic disease, and malignant neoplasm) were associated with a lower susceptibility to heat and were found to be most prevalent among the subjects included in the lower class of the AS score. However, these pathologies are also associated with higher general risk of mortality, independently of heat waves, which is consistent with the high mortality rate characterizing this class. Lower heat susceptibility in the subjects who had had previous hospital stays was probably due to more attentive monitoring by health services, especially during heat waves.

Every year, this indicator is used in Rome to produce a list of susceptible subjects to be targeted by prevention programs. The 65–74 and 75+ age groups are classified according to the RS and AS indicators, respectively. Through a record-linkage procedure, which is based on the subjects' variables included in the indicator, scores are assigned to all residents in Rome over 65 years of age. By design, all subjects with the same combination of clinical and sociodemographic characteristics receive the same score values. Those with scores above a certain threshold, determined a priori according to budget constraints, are then selected to be included in the prevention program.
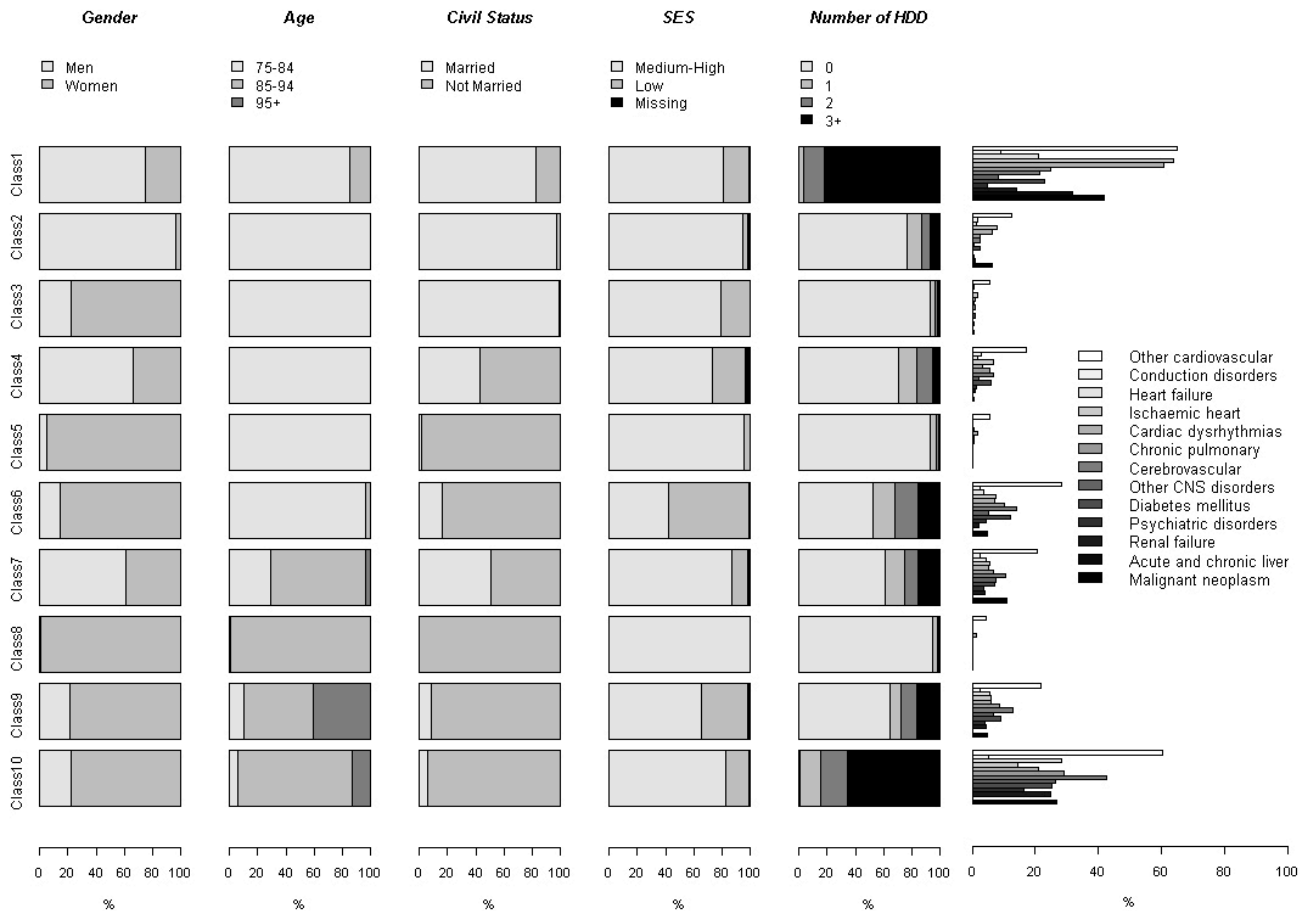
Figure 3. Classes of the susceptibility indicator for the 75+ age group cohort

SES: socioeconomic status; HDD: Hospitalization Diagnosed Disease; CNS: Central nervous system

In Italy, other cities have adopted different procedures for identifying susceptible subgroups [11]. These employed methodologies greatly differ and are usually based on the identification of subjects with specific conditions known to be associated with heat susceptibility (usually age and previous hospital stays, as well as social and economic conditions, when information is available), which is retrieved from administrative databases or through active notification by health/social workers. However, these various methodologies determine heterogeneity of characteristics and size of the selected population, and all have a certain degree of subjectivity. The susceptibility indicator developed in Rome might represent a standardized procedure that can overcome the inherent subjective component involved with other selection procedures, and may even be employed in other contexts [11].

Some limitations regarding the indicator are worth mentioning. The indicator was designed to identify a sufficiently small subgroup of high-risk elderly individuals who should be targeted by preventative activities during heat waves. This goal was more efficiently achieved in the 65–74 year-old group, where the subjects with the highest relative risk of dying were included in the two classes with the highest scores. In contrast, among the 75+ age group, five of the ten classes of the indicator were associated with increased risk of dying during heat waves. This finding might be due, at least in part, to the high baseline mortality observed in this age group, which influences AS score values, and the high prevalence of risk factors that enhance heat susceptibility. However, the two classes with the highest AS score revealed subjects with the highest risk difference within the validation population, allowing this indicator to be used efficiently in practice.

Another point of discussion is the exclusive use of information retrieved from current administrative databases in the construction of the indicator, which may constitute both a strength and a limitation of the indicator. Indeed, this feature of the indicator allows it to be used without an ad hoc collection of data, making this approach more economically sustainable; however, this may simultaneously limit the data included. With regard to medical conditions, hospital admissions may not be the most accurate measure of disease prevalence in our population, especially for chronic pathologies, which are difficult to diagnose and unlikely to lead to an admission [3]. Moreover, hospital counts reflect both the underlying prevalence of disease as well as provider-specific factors (i.e., the availability and supply of primary care and outpatient services) [22,23]. These limits could be partially overcome by using additional health data sources (e.g., outpatient care and pharmaceutical prescriptions). In particular, data from pharmaceutical databases might provide more valid estimates of disease prevalence of long-term conditions (e.g., diabetes) [24,25]. Moreover, information on social factors are usually unavailable in administrative archives [1,2]. Here, the use of marital status as a proxy for living alone is clearly biased, but no alternative information was readily available.

Another critical point relates to the definition of heat wave used in our study, which could alter the results. Nevertheless, we applied the same definition of heat wave used in the HHWWS to trigger alarms, which are used to activate preventive measures [11]. Indeed, in a recent study comparing the predictive capacity of various heat warning systems, it was found that methods similar to the Italian one performed better (based on the association between temperature and mortality) [26].

Conclusions

The indicator of heat susceptibility developed here can be effectively used to identify subjects with increased risk of mortality during heat-wave episodes on the basis of individual sociodemographic and health characteristics retrieved from administrative data. So far, no other standardized, reliable, population-specific, and economically affordable approach has been proposed for the selection of heat susceptible subjects. This method can aid public health decision-makers in addressing heat response activities. Indeed,

it can help maximize cost-effectiveness and facilitate GPs to identify at-risk subjects requiring more clinical attention during extreme heat waves.

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