Chapter 20
The Effect of Heat Stress on Daily Mortality in Tel Aviv, Israel

[AU1] **C. Peretz, A. Biggeri, P. Alpert, and M. Baccini**

Abstract Weather-related morbidity and mortality have attracted renewed interest because of climate changes. During a multi-center project conducted within Europe, the threshold temperature where the "heat effect" changes was found to be different for Mediterranean and north continental cities. In this paper, we study the V/J relationship between heat stress (Discomfort Index-DI) and mortality in Tel Aviv, a city within Asia, using daily data of mortality counts and meteorological variables for the period 1/1/2000–31/12/2004 using a Poisson regression and accounting for confounders. The relationship between the discomfort index DI (lag 0–3) and log mortality rates was J shaped for Tel Aviv. The DI threshold was found to be 29.3 (90% CrI = 28.0–30.7). Above this threshold, a 1 unit increase in DI was found to be associated with increased mortality of 3.72% (90% CrI = −0.23 to 8.72). NO_2 was also found to have a significant effect on mortality. As global warming continues, even though there exists a high awareness amongst the Israeli population of the negative health impacts of heat, there is still a vital need to develop local policies to mitigate heat-related deaths.

Keywords Heat stress • Mortality • Global warming • Mediterranean cities

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[AU1] C. Peretz (✉)
Department of Epidemiology, Faculty of Medicine, Tel Aviv University,
Tel Aviv, Israel
e-mail: cperetz@post.tau.ac.il

A. Biggeri • M. Baccini
Department of Statistics "G. Parenti",
University of Florence, Florence, Italy

P. Alpert
Department of Geophysics, Faculty of Exact Sciences,
Tel Aviv University, Tel Aviv, Israel

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20.1 Introduction [AU2]

Weather-related morbidity and mortality have attracted renewed interest because of climate changes. Specifically, the short-term effects of temperature on mortality have recently been studied in Europe [1–3], Australia [4] the US [5, 6], East Asia [7], and other places [8], and display a seasonal pattern with increased mortality in cold and hot temperatures (a V or J shape). Within Europe, in the multi-center project of PHEWE (Assessment and Prevention of acute Health Effects of Weather conditions in Europe), a threshold apparent temperature – a point where the heat effect changes, was found to be different between Mediterranean and north continental cities [1]. This difference is related to the fact that populations adapt to their local climate—physiologically, culturally and behaviourally.

In South-Eastern Mediterranean cities in West Asia, such as Tel Aviv, the climate-mortality association has not yet been investigated (except for Beirut in the years 1997–1999 [9]. Tel Aviv is the second largest city in Israel and is situated on the East Mediterranean coast, with warm to hot, dry summers and cool, wet winters. Compared to European Mediterranean cities, there are many more hot days throughout the year as well as episodes of resuspended wind-blown dust from the Sahara desert, mainly in spring. Air pollutants are potential confounders in the association between temperature and mortality [5]. In Tel Aviv, the main source of air pollution is heavy traffic and to a lesser extent power stations and industrial zones.

For the calculation of valid indices that define heat stress and zones of discomfort, many physiological and environmental factors are required. In Israel, we use the discomfort index (DI) as an index for human thermal comfort [10]. This index involves two environmental factors, temperature and relative humidity and is similar to the index of apparent temperature (AT) which is common in studies on the short term effects of heat on health [11]. Since Tel Aviv differs from European Mediterranean cities in climate, culture and inhabitants' behaviour, especially with regard to a high use of air conditioners and a high awareness of water/fluid consumption, our aim was to study the V/J relationship between heat stress and mortality in Tel Aviv, while estimating a threshold heat-stress (DI) point (where the heat-stress effect changes) during the whole year in a time-series design.

20.2 Methods

The data was collected for the Tel Aviv area for the period 1/1/2000–31/12/2004 in a time-series design [6].

20.2.1 Health Data

The Israel Ministry of Health provided daily mortality counts, referring to the city residences. Taking into account the results of previous studies and the biological plausibility of the health effects [12], the following causes of death were selected for all ages combined and specific age groups (0, 1–14, 15–44, 45–64, 65–74, 75 + y): all causes (except external causes) ICD-9: 1–799; cardiac diseases ICD-9: 390–429; circulatory system diseases ICD-9: 440–459; and respiratory diseases ICD-9: 460–519. The gender was stamped in the data set.

20.2.2 Meteorological Data

The Israel Ministry of Environmental Protection provided data from monitoring stations located in the city for the entire study period. For this study, we focused on air temperature and relative humidity recorded every half hour. Mean daily averages of all stations were calculated for each variable. Quality control included a descriptive overview of the variables, detecting possible errors and extreme values, testing for homogeneity and correcting erroneous values where possible.

20.2.3 Exposure Assessment

We focused on the effect of the discomfort index on mortality, according to the following formula that involves temperature (Temp) and relative humidity (RH) as [AU3] both additive and multiplicative factors [10]:

$$DI = -0.394479 + 0.784533 \times Temp + 0.022226 \times RH + 0.0023765 \times Temp \times RH$$

This index has been used for more than four decades and is highly correlated with the effective temperature index and with the wet-bulb globe temperature (WBGT) heat stress index that was developed in the US Navy as part of a study on heat related injuries during military training. From a biometeorological perspective, this index is more logical than describing temperature and humidity separately. The common categorization of DI, based on studies of populations from different climate conditions and ethnicity is: <22 (no heat stress), 22–23.9 (mild), 24–27.9 (moderately heavy), and >28 (severe heat stress). The Israeli Defense Forces has adopted this categorization for guidelines for exercising in heat. Daily values of DI were computed based on daily average values of temperature (°C) and relative humidity.

20.2.4 Air Pollution Data

The following pollutant half-hourly measurements were collected from six monitoring stations in Tel Aviv which are part of the air-quality network of the Ministry of Environmental Protection: CO (maximum 8-h moving average); O_3 (daily maximum, maximum 8-h moving average); NO_2 (daily maximum, daily average); SO_2 (daily average); TSP or Black Smoke (daily average); PM_{10} (daily average); and $PM_{2.5}$ (daily average). Monitor selection was based on local criteria, mainly on the completeness of measurements and representation of population exposure. A standardized procedure was used to fill in days with missing data [12]. Since different stations differ in monitored pollutants, we estimated a mean maximum/average daily value of all data available for each pollutant.

For this study, we used the maximum hourly value of nitrogen dioxide (NO_2) as an indicator of the overall daily air pollution level for the entire city.

20.2.5 Tel Aviv – General Characteristics

Characteristics of Tel Aviv are presented in Fig. 20.1. The area of the city is about 50.5 km^2 and the population in the years 2001–2004 grew from 358,800 to 371,400 inhabitants. On average, 8.8 inhabitants died per day during the summers and 10.3 died per day during the winters of 2001–2004. About 80% of households have air conditioners.

20.2.6 Statistical Modeling

A Poisson regression model was specified for the daily death count using a Bayesian approach [1]. We included in the model dummy variables for the day of week and calendar month and a linear term for the maximum hourly NO2 concentrations (lag 0–1). We modelled the relationship between DI (lag 0–3) and mortality by two linear terms constrained to joint in a point (threshold), using R software.

The model for the daily number of deaths (y_i) was the following:

$$y_i \sim Po(\mu_i)$$

$$log(\mu_i) = \alpha + month_i + wday_i + \beta \times poll_i + \gamma_0 \times T_i + \gamma_1 \times (T_i - threshold)_+$$

$$(T_i - threshold)_+ = \begin{cases} (T_i - threshold) & T_i > threshold \\ 0 & T_i \le threshold \end{cases}$$

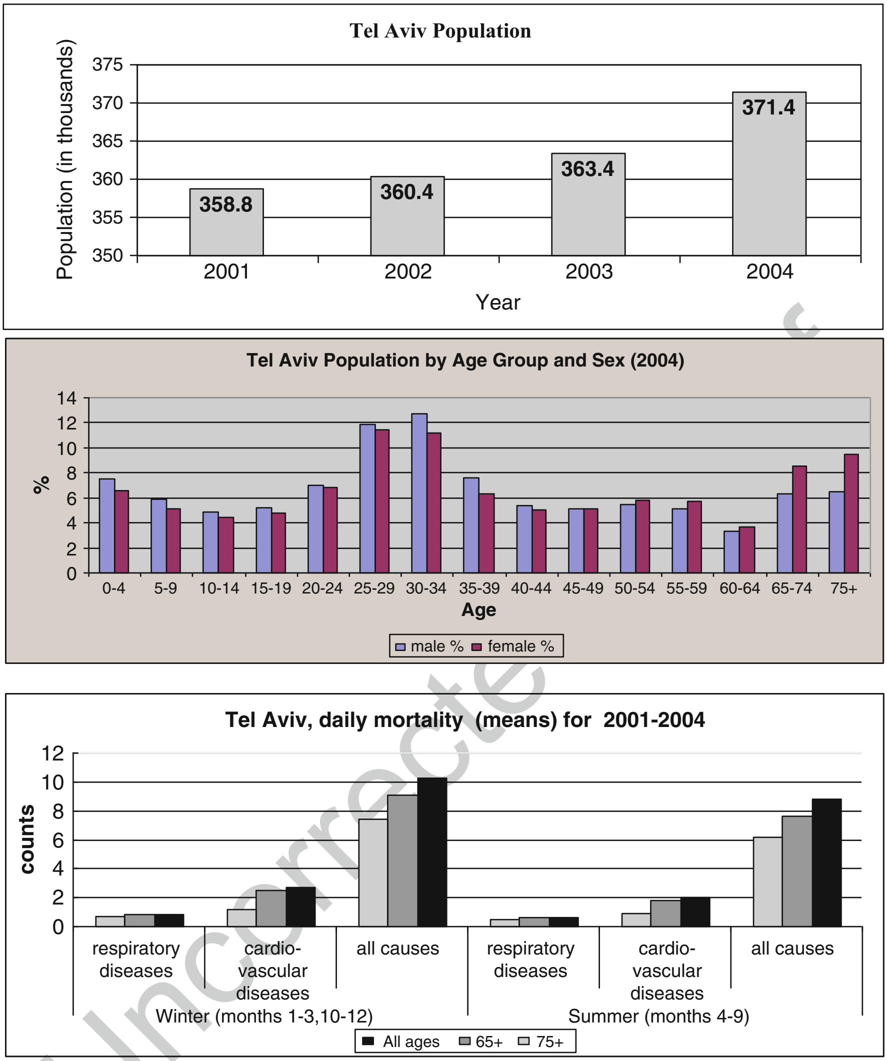


Fig. 20.1 Tel Aviv population (2001–2004)

The threshold, a value of DI which corresponds to a change in the effect estimate, was considered as an unknown parameter to be estimated. A normal prior distribution with large variance, centered in 24, was specified for the threshold. Non-informative prior distributions were specified on all regression coefficients. The joint posterior distribution for the model parameters was obtained using MCMC methods, with the software WinBugs 14. Posterior mean and 90% credibility intervals are provided for the parameters of interest.

20.3 Results

Table 20.1 presents summary statistics of meteorological data during the summer in Tel Aviv (months 4–9) in comparison to other Mediterranean European cities (18). The mean AT temperature in Tel Aviv was found to be the highest among these cities and the relative humidity was also high. Figure 20.2 presents daily data of temperature, discomfort index and relative humidity as well as NO_2 levels during the study period (2001–2004) in Tel Aviv.

20.3.1 Exposure-Response Relationship

The relationship between the discomfort index DI (lag 0–3) and log mortality rates was J shaped for Tel Aviv (Fig 20.4). This indicated a linear excess risk to die for exposures to heat stress above a threshold. The DI threshold for Tel Aviv was found to be 29.3 (90% CrI = 28.0–30.7), a value considered to be a severe heat-stress (DI > 28). We report the heat effect as percent change in mortality associated with a 1 unit change in DI above/below the threshold. Above the threshold of 29.3, a 1 unit increase in DI was found to be associated with borderline significant increased mortality of 3.72% (90% CrI = −0.23 to 8.72). However, below the threshold a 1 unit decrease in DI was found to be associated with a non-significant

Table 20.1 Meteorological data in Tel Aviv and European Mediterranean cities, during the summer (months 4–9); mean, min-max

		Meteorological variables		
City	Study Period	AT[a]	Temperature[b]	Relative-humidity
Tel Aviv	2001–2004	32.4	25.5	71
		14.0–45.3	13.9–33.8	22–90
Valencia	1995–2000	29.5	22.3	66
		10.6–44.9	10.5–30	32–92
Athens	1992–1996	27.9	23.5	57
		7.9–41.6	7.6–34.3	23–89
Rome	1992–2000	26.1	20.5	72
		5.9–40.5	6.1–30.3	25–94
Milan	1990–2000	25.4	20.0	72
		2.7–40.8	2.5–29.4	26–100
Turin	1991–1999	23.4	18.5	74
		4.2–45.8	3.0–27.9	32–97
Barcelona	1992–2000	23.3	21.7	66
		6.5–36.9	8.6–34.2	29–99
Ljubljana	1992–1999	20.1	15.9	75
		−1.7 to 35.4	0.6–26.5	33–98

[a]Apparent temperature in °C, $AT = -2.653 + .994 * temp + .0153 * (dew)^2$

[b]In Tel Aviv it's a daily average AT while in the other cities it's a daily max AT

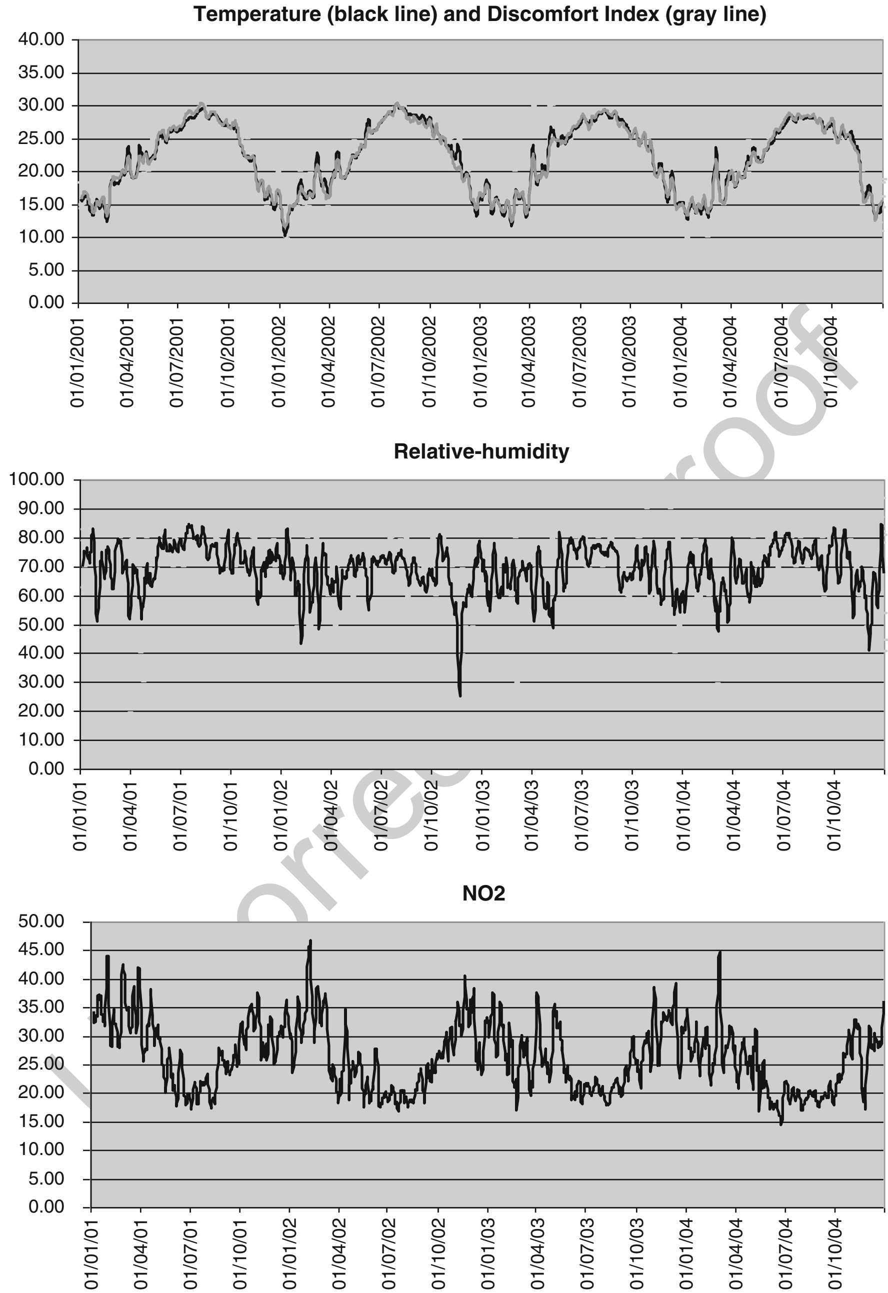
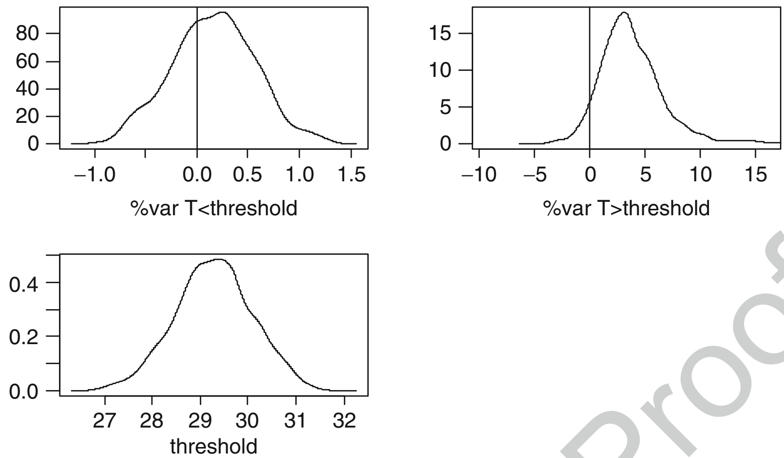


Fig. 20.2 Daily data of temperature (average in °C), discomfort index, relative humidity (average) and NO_2 levels (maximum in ppb), Tel Aviv 2001–2004; smoothed time series (7 day moving average)

a

The full posterior distribution



b

Posterior means and 90% credibility intervals

	Posterior mean	90% Credibility interval	
% variation under the threshold	0.15	–0.54	0.80
% variation over the threshold	3.72	–0.23	8.72
Threshold	29.28	27.96	30.65

Fig. 20.3 (a) The posterior distribution of the percent variation under the threshold. (b) The percent variation over the threshold and of the threshold (in DI)

increase in mortality of 0.15% (90% CrI = –0.54 to 0.80), which can be considered to be 0% (Figs. 20.3 and 20.4). NO_2 was found to have a significant effect on mortality; an increase in 10 ppb was associated with an increase in mortality of 2.45% (90% CrI = 0.44–4.49).

20.4 Discussion

In this work we found a threshold heat-stress for Tel Aviv of DI = 29.3 (90% CrI = 28.0–30.7), a value 1.3 units higher than the lower value of severe heat-stress (DI = 28) [10]. In 2001–2004, 4% of the days were above this threshold and 15% were above DI = 28. This threshold value of DI = 29.3 for Tel Aviv is probably related to our specific health outcome, which was mortality rather than morbidity. Furthermore, we found that a 1-unit increase of DI above the threshold corresponded to a 3.7% increase in daily mortality, of borderline significance. A single day with a DI heat-stress exceeding the threshold noted above is sufficient to cause this increase

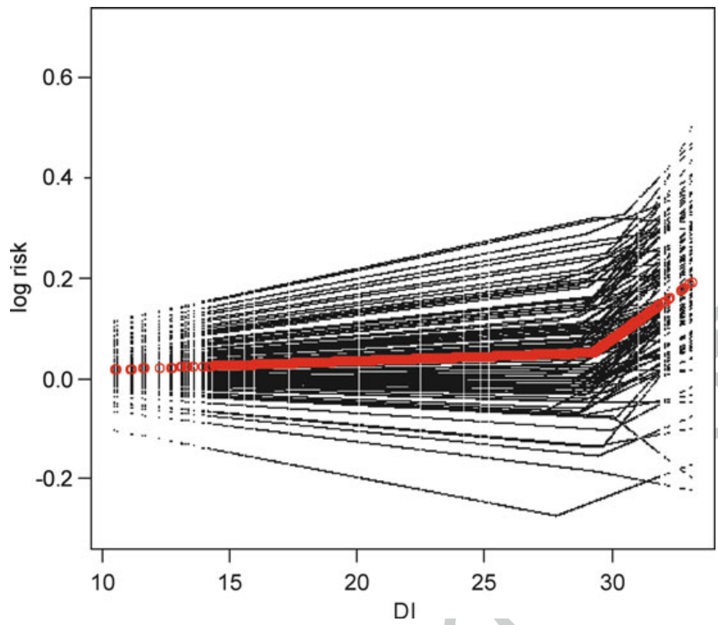


Fig. 20.4 Relationship between heat stress (in DI units) and mortality

in mortality, rather than requiring an extended heat wave. These results for Tel Aviv might not be relevant to other inland cities in Israel with different climatic conditions, especially with regard to humidity (*e.g.*, Beer Sheva and Jerusalem) or to rural areas. It is also difficult to directly compare our results with other epidemiological studies on heat and mortality because of methodological differences [11] such as: the use of heat-stress definition- either ambient average/max daily temperature [3, 4, 8, 9] or apparent temperature [1, 2, 6, 7]; the way of reporting on heat effects – above a threshold value [1, 3, 7–9] or not [2, 4, 6]; the approach of estimating a threshold value – based on a statistical method of maximum likelihood [1, 7, 8] or on inspection of the exposure-response curves [3, 9]; a mix of seasons were included in the study and only the warm seasons were included in [1, 2, 4, 6] or all seasons were included in [3, 7–9]. After accounting for some methodological differences, our results are in agreement with those that have been obtained from European Mediterranean cities (that is, for a J shape relationship with a threshold of 29.4°C AT (29.3 DI) and quite a similar percent increase in mortality above the threshold, even though the higher average of AT temperature in Tel Aviv during the summer). However, the percent increase is less significant and this might be explained by the heterogeneity of Tel Aviv's population with regard to socio-economic status, nationality (Jews and Arabs), immigrant status (newcomers from the former USSR or not), or by high use of domestic air conditioning in Israel, the air conditioning of public buildings due to mandatory building regulations [13], and behavioural adaption of the elderly that stay at home on hot days.

Interestingly, comparing Tel Aviv and Mediterranean European cities to Korean cities [11] with different levels of temperature and humidity, the mortality estimates above a similar threshold (Korea: 23.3–29.7°C of AT) resulted in a much higher effect in Korea – an increase of 6.73–16.3% (in six cities) in mortality per 1°C increase of AT compared to 3.7% (per 1 DI unit) and 3.1% (per 1°C AT) in Tel Aviv and Mediterranean European cities, respectively. Two recent American studies suggested that the effect estimates throughout California and other parts of the US are similar, even with different ranges of apparent temperatures. They both found an approximately 2% increase in mortality per a 10°F increase in apparent temperature [11], a smaller increase than reported above. It should be noted that these studies differ also in other methodological issues: in the study designs (time series or case-crossover); the lag-days that were considered (*e.g.*, 0, 0–4, 2-day average); the study time-period; the cause-specific mortality (*e.g.*, all cause or specific causes) and age-groups that were considered (*e.g.*, mortality of all ages or 65+); as well as in the statistical modelling.

The role of the following air-pollutants: O_3, PM_{10}, $PM_{2.5}$, CO and SO_2 as confounders and/or effect modifiers on the temperature-mortality association were found to be mixed; some investigators reported air pollutants as confounders or effect modifiers while others found no significant confounding or effect modification in their studies [11]. We found a significant effect of NO_2.

Our study has some major strengths. It is the first study of this kind in Israel. The exposure index was DI and not just temperature or relative humidity, and we adjusted for the possible confounding effects of air pollution. We suggest that further studies in Israel should focus on sub-districts and that they should examine heat-stress and different causes of death, define heat waves and examine their effect on mortality and consider max temperature during the day and max temperature during the night. To conclude, as global warming continues, the frequency, intensity and duration of heat stress days are likely to increase and even though there exists a high awareness amongst the Israeli population to the negative effect of heat on health, there is still a vital need for local policies to mitigate heat-related deaths.

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