Beating the Heat: Development and Evaluation of a Canadian Hot Weather Health-Response Plan

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An increasing number of cities subject to hazardous summer weather in the United States and Canada have begun to develop and implement hot weather response plans to prevent heat-related illnesses and deaths. In this study we focus on heat–mortality relationships in Toronto, Ontario, between 1980 and 1996 and evaluate the potential effectiveness of the city's interim hot weather-health response plan. Using two heat stress indexes—humidex and apparent temperature—we identified excess mortality associated with hot and humid weather and then estimated excess deaths for hot and cool summers. Mortality rates for all ages and for > 64 years age groups rose with increasing humidex and apparent temperature, with no significant increase for the population < 65 years. Excess mortality occurred as low as the 30–35°C humidex range, which is below the 40°C humidex used to issue a heat warning under Toronto's interim hot weather response plan. During a hot summer (such as 1988 or 1995), 32 excess deaths would be expected, whereas 34 fewer deaths than baseline levels would be expected during a cool summer like 1982 or 1992. Days with high humidex levels occur infrequently in Toronto, and thus exposure is limited under current climatic conditions. In the event of a warming climate, more days with dangerously high humidex levels are likely to occur, and summer deaths are expected to increase. Toronto's hot weather health-response plan is an important early step for adaptation to climate change. *Key words*: apparent temperature, Canada, heat index, heat-related mortality, heat stress, heat wave, hot weather, humidex, Toronto. *Environ Health Perspect* 109:1241–1248 (2001). [Online 29 November 2001]

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As the July 1995 heat wave in Chicago demonstrated, episodes of hot and humid weather can lead to hundreds of excess deaths over several days. An increasing number of cities subject to hazardous summer weather across the United States and Canada have begun to develop and implement hot weather response plans to prevent heat-related illnesses and deaths. In this study we focused on heat–mortality relationships in Toronto, Ontario, Canada, between 1980 and 1996 and evaluated the potential effectiveness of the City of Toronto's interim hot weather health-response plan.

In the summer of 1999, Toronto experienced an extended episode of hot weather. Arising from this event was concern about the health of high-risk populations, particularly those who are homeless, elderly, ill, or socially isolated. In the event of a changing climate, relationships between summer weather and health may worsen, causing more deaths and illnesses (*1–4*). In response to these concerns, over the past 2 years Toronto Public Health has been developing a heat wave alert system for the city. Key components of the Toronto heat response plan are to designate the weather conditions that will be used for calling a heat alert, under which extended health and social services will be made available, and a heat emergency, which will involve more drastic prevention measures and considerably more expense.

To assess the usefulness of heat stress indexes in identifying episodes of hot weather that are detrimental to human health, we compared the relationships identified between hot weather and mortality by using various levels of two commonly used indexes: humidex and apparent temperature (AT). We also estimated the number of excess deaths for hot and cool summers. Our ultimate objective is to provide information that will help public health agencies identify heat stress conditions that are likely to be harmful to human health so they can implement appropriate health services. This step is also an important part of adaptation to climate change.

Toronto is located on the north shore of Lake Ontario. As of 1996, 4.26 million people resided in the newly amalgamated City of Toronto (hereafter referred to as Toronto), which is composed of the city proper, as well as five additional contiguous boroughs (*5*). The area experiences relatively cold winters as well as hot and humid summers. Although mean summer temperatures range from 17° to 20°C, temperatures of 26°C or higher occur in most summers (*6*). Climate model simulations have suggested that temperatures in southern Ontario will warm between 2° and 5°C by the end of the twenty-first century (*7*), so Toronto is likely to experience more frequent episodes of hot and humid summer weather. Although this study is specific to Toronto, we anticipate that the findings will be useful to policy makers in other North American cities concerned with the health effects of hot and humid summer weather.

Heat and Human Health

Extreme heat is a well-known cause of heat stroke, heat syncope, and heat cramps, and it also exacerbates many preexisting health conditions, elevating morbidity and mortality. For example, the heat waves of 1980, 1983, and 1988 were determined to be directly responsible for more than 2,700 deaths across the United States (*8*). These numbers are higher if all excess deaths (i.e., deaths above the expected baseline), rather than only those classified as directly heat related, are included. In Canada, summer weather has been linked to increased mortality and morbidity in urban centers within southern Ontario and the St. Lawrence River area (*1,2,9,10*).

Populations at particularly high risk include the elderly, those on certain medications, and those with preexisting illnesses, particularly if they reside in cities (*8–14*). The timing of the event and its duration have also been shown to be important, with heat waves occurring early in the season having higher associated mortality than those later in the season. In addition, prolonged hot conditions are more stressful to human health than isolated hot days (*2,13,14*).

Health promotion and adaptation through weather watch/warning systems. Heat stress conditions are predictable, and heat stress mortality is preventable. As do most public health interventions, measures to reduce impacts (in this case, of heat) can involve modifications to both environment and behavior (*15*). Environmental modification in the form of air conditioning, shaded

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dwellings, light-colored building materials and road surfaces, and well-placed vegetated areas provides ongoing and passive (i.e., not requiring immediate action from at-risk individuals during heat events) heat stress risk reduction. A "Cool Toronto" initiative, under the Toronto Atmospheric Fund, is investigating issues of urban adaptation to summer heat, including environmental modification (16).

Although the benefits to public health may not be as significant as from environmental modification, behavioral modification during heat events is often more feasible and economically practical, at least in the short term. Education and awareness are key components of behavioral modification and may include recommendations such as seeking cool shelter, reducing activity, drinking fluids, and checking on elderly relatives and neighbors during heat events. Like passive health interventions, active risk reduction strategies require planning well in advance of the summer season, but costs are likely to be lower and implementation less complicated than environmental modification. Typically, these actions commence when a heat wave is forecast or already occurring. Effective communication at the onset of a dangerous weather event is a crucial component of weather watch/warning systems and emergency preparedness plans. An increasing number of North American cities have implemented or are developing weather watch/warning systems as a way to reduce the harmful effects of heat stress (e.g., Philadelphia, St. Louis, Chicago, Toronto).

Weather watches, warnings, and advisories are frequently used to convey forecasts of severe weather to the public. In Canada, this information is used for events such as cold snaps, storms, and high winds, but rarely for heat waves (17). Typically weather watch/warning systems involve a two-tiered system of a "watch" or "alert" when a particular level of heat stress occurs or is forecast, and an "emergency" stage when heat stress becomes potentially very dangerous and more drastic action is needed. The combined effort of city managers, public health and social services workers, and emergency medical officers is needed to develop a systematic plan that will provide assistance to the most vulnerable populations. Public health interventions may include a diverse range of activities including the operation of cooling shelters and education campaigns about the harmful effects of hot weather and how to avoid its impacts.

Heat wave watch/warning systems first require the definition of heat stress events. The challenge lies in determining at which point heat stress conditions become sufficiently hazardous to human health to warrant public health interventions. If too low a level of heat stress is used, then watches or

emergencies will be called too often. As a result, the public may not take them seriously, and unnecessary expenses are incurred. Using too high a level, however, would pose an unacceptable health risk.

Defining Harmful Hot Weather Events

Many methods for defining heat stress exist: univariate, bivariate, and multivariate indexes; air mass typologies; and absolute and relative approaches. Univariate heat stress measures typically designate subjective cut-off points above which health effects are expected to occur. Examples include mean or maximum temperature levels (e.g., 30°, 35°, 40°C, etc.) or the number of consecutive hours or days above some specified temperature. Bivariate indexes, such as humidex (18), usually include temperature and humidity. Multivariate indexes, such as apparent temperature—also known as the heat index (19,20)—tend to incorporate some combination of wind speed and/or solar radiation that affects the body's ability to dissipate heat. Rosenberg et al. (21) provide a more detailed description of various weather stress indexes.

The most meteorologically representative, and often the most complex, indexes use air masses. Air mass typologies use a combination of weather variables to identify air masses, or bodies of air with similar meteorologic conditions. Currently, the World Health Organization, with other agencies, is funding a host of showcase watch/warning systems in major cities, including Rome and Shanghai, that use an air mass-based approach (22). This method has been successful in Philadelphia (23) and is scheduled to be implemented in several cities in Ohio (24).

Any weather index can be used as an absolute or relative measure of heat stress. Absolute approaches implicitly assume that

all populations respond similarly to each successive level of heat stress. On the other hand, relative approaches such as threshold temperature (25) take into account that different populations respond differently to heat stress. Other considerations for heat stress indexes include factors such as the onset of the event (e.g., early or late in the summer season), the duration of the event, concurrent air-quality levels, microclimatic variation, or high-risk populations.

Apparent temperature (AT), or the heat index, is perhaps the best known and most widely used heat stress index. The Canadian weather service uses the Canadian-developed humidex, rather than AT. Both indexes incorporate temperature and humidity (Table 1). In their original form, both humidex and AT are absolute rather than relative indexes in that they have predetermined health impacts associated with various levels of the index.

The indexes presented here represent just a fraction of the many in existence and that are continually being refined or created. Depending on the intended application, the following points need to be considered before selecting a heat index for use:

1. How well does the index represent the actual weather situation and within the range of values of interest?
2. Can the index be derived relatively simply from readily available daily weather data?
3. How accurate are forecasts using the index?
4. How closely do changes in the index reflect the severity of health impacts?

For use in heat wave watch/warning systems, it is imperative to ascertain whether the heat stress index can identify a level above which excess deaths occur, because this value will be used to initiate public health responses. Because a wide variety of people with different backgrounds may need

Table 1. Comfort levels and health outcomes associated with different values of humidex and apparent temperature.

Range (°F)	Range (°C)	Health impact
Humidex[a]		
< 86	< 30	No discomfort
86–103.9	30–39	Some discomfort
104–113	40–45	Great discomfort, avoid exertion
> 113	> 45	Dangerous
> 129.2	> 54	Heat stroke imminent
Apparent temperature (heat index)[b]		
80–90	26.7–32.2	Fatigue possible with prolonged exposure and/or physical activity
90–105	32.2–40.6	Sunstroke, heat cramps, and heat exhaustion possible with prolonged exposure and or physical activity
105–130	40.6–54.4	Sunstroke, heat cramps, or heat exhaustion likely, and heatstroke possible with prolonged exposure and/or physical activity
> 130	> 54.4	Heatstroke/sunstroke highly likely with continued exposure

[a]Data from Environment Canada (26). [b]Data from U.S. National Weather Service (27).

to use the index, it is also important that the index be user friendly. And because heat alerts and emergencies must be called in advance, forecast conditions should be relatively accurate, although their precision is less important. In other words, it is important to know whether very hot and humid conditions are likely to occur and to persist, but forecasting precise air or dewpoint temperatures is less consequential. Thus criteria 2, 3, and 4 are more important for public health applications than the first criterion. In keeping with these criteria, we selected humidex and AT for our assessment of a heat wave/watch warning system.

Toronto's interim hot weather response plan. Humidex, rather than AT, is widely used in Canadian weather reports and in the Canadian media, and has meaning to the general public (*28*). Toronto Public Health's (TPH) interim hot weather response plan suggests using a predicted or observed humidex of 40–45°C (with an air temperature of at least 30°C) to initiate a heat warning, and a predicted or observed value of 45°C or above to issue a heat emergency. More recently, Toronto has decided to call heat warnings when the humidex is predicted to be > 40°C for 2 consecutive days (*29*). Under the proposed plan, Environment Canada would notify TPH each morning of predicted humidex levels for that day and the following day. The Medical Officer of Health would declare a heat warning if the predicted humidex were between 40°C and 45°C. Then various media, public services, and health organizations would be notified to disseminate information for coping with heat waves. Cool-air refuges such as libraries would open or extend their hours. Red Cross would provide staff and transport to public facilities, while street patrols would be available to communicate heat risk to homeless persons, distribute bottled water, and provide transit tokens to access cooling sites. The strategy for heat emergencies, to be called when the humidex exceeds 45°C, has yet to be determined (*28*).

To our knowledge, the homeless population has not received special attention in U.S. heat/health studies or hot weather response plans, as has been the case in Toronto. To investigate the potential of elevated mortality risk among the homeless, we reviewed heat-related fatalities occurring in the United States since 1995. We found that by far the largest number (composing 68–89%) of directly heat-related deaths occur from exposures within the home, rather than outdoors or in the workplace (*30*). The U.S. statistics indicate that homeless persons are likely to be at lower risk than those in older housing lacking (or not using) air conditioning. There has been concern that

the number of operative municipal drinking water fountains in Toronto is insufficient (*31*), which could severely affect the homeless as well as the general public during heat wave conditions. Following TPH's recommendations, the City of Toronto has adopted a clause providing for the distribution of bottled water to the city's homeless population (*32*).

TPH has noted incompatibility in the AT and humidex indexes that prevents ready conversion of AT, which is used in many U.S. hot weather response plans, to humidex. Using weather and mortality data from 1980 to 1996, we demonstrate a method for comparing the two indexes. We then evaluate the mortality impacts associated with weather conditions sufficient to call heat warnings and emergencies according to TPH's 1999 interim plan.

Materials and Methods

For 1 May–30 September, for each year from 1980 to 1996, Environment Canada provided hourly values of air temperature and dewpoint temperature from the weather station at the Toronto Pearson International Airport in Etobicoke, which is located approximately 15 km from downtown Toronto. These dates were selected, rather than 1 June–31 August, to ensure that we captured hot weather occurring in the "shoulder" summer season. We used daily maximum air temperature and the dewpoint that occurred at the corresponding hour to calculate apparent temperature and humidex. The original method of calculating apparent temperature involves a complex set of equations based on heat transfer coefficients of physiologic equilibrium (*19,20*). But because simplicity in calculation is important for public health applications, we derived a two-variable equation by regressing values from published tables of air temperature, dewpoint temperature, and apparent temperature [available in Steadman (*19*), p. 871]. Thus, only air temperature and dewpoint temperature, for which daily values are available from hundreds of weather stations across Canada and the United States, are needed to calculate AT. The U.S. National Weather Service also has on its website tables and a calculator for finding AT from air temperature and dewpoint or relative humidity (*27*). The service's calculations, however, are based on a different, and more complex, equation than the one we use here.

We calculated daily apparent temperatures (assuming no or light winds) in °C following Steadman (*19*) as follows:

$$AT = -2.719 + 0.994\,T_a + 0.016(T_d)^2, \quad [1]$$

where T_a = air temperature (°C), T_d = dew point temperature (°C), and AT = apparent temperature (°C).

Calculation of humidex is more complex than the simplified form of AT; however, lay users can bypass this step and obtain humidex directly from Environment Canada for a fee. Daily values of humidex were calculated according to Masterton and Richardson's (*18*) equation:

$$Humidex = T + h, \quad [2]$$

where T = dry-bulb temperature (°C) and

$$h = \frac{5}{9}(e - 10). \quad [3]$$

The term h is an inflation factor to account for humidity. The term e is the vapor pressure calculated using a modified form of the Clausius-Clapeyron equation that relates temperature to pressure as follows:

$$e = 6.11\left[\exp\left(\frac{M_w L}{R}\right)\left(\frac{1}{273.16} - \frac{1}{T_d}\right)\right], \quad [4]$$

where 6.11 = saturation vapor pressure (millibars) at a standard temperature of 273.16 K, M_w = molecular weight of water (constant), L = latent heat of vaporization (constant), R = universal gas constant, 273.16 = melting point of ice (kelvin), and, T_d = dewpoint temperature (kelvin).

Because both AT and humidex are intended to represent heat stress conditions, the indexes are not meaningful at cool temperatures. Therefore, for dry bulb temperatures < 25°C, AT and humidex values were assigned to dry bulb temperature. We also used this substitution for humidex for dry bulb temperatures ≥ 25°C when the humidity inflation factor h was negative.

For the 17-year period 1 May–30 September 1980–1996, the study used daily mortality data from the combined census subdivisions (similar in size to a U.S. county) of Toronto, East York, York, North York, Scarborough, and Etobicoke, which compose the newly amalgamated City of Toronto. Only nonaccidental causes of death were included—deaths with *International Classification of Diseases, Ninth Revision* (ICD9) codes <800 or 992. We analyzed all nonaccidental causes of death for the total population, the population age 65 and older (≥ 65), and the population under 65 years (< 65). We used all causes of death because using heat stroke or other directly heat-related causes of death severely underestimates the effects of hot and humid weather on human mortality (*8,25*).

After calculating apparent temperature and humidex, we used AT values in a regression equation to predict humidex values and to assess the level of association between the

two indexes. For the all-ages, < 65, and ≥ 65 age groups, we first calculated mortality rates for the different ranges of apparent temperature and humidex for which health or comfort effects have been noted previously (Table 1). We then used difference of means tests to compare mortality for each category to baseline mortality.

Method for estimating excess deaths. For public-health planning purposes, it is useful to estimate the number of excess deaths (i.e., those above baseline levels) associated with each heat stress category, as well as those that might be expected in Toronto under different climate scenarios. To illustrate the average number of deaths per summer associated with different levels of heat stress, we multiplied the mortality rates calculated for each humidex and AT category by the mean number of days occurring in each category. We then multiplied these values by the 1996 population for each age group. The resulting numbers take into account both the virulence of the heat stress conditions as well as the exposure, in terms of average days of occurrence per summer. These values can then be compared with estimates of excess deaths under different weather scenarios.

Our next step was to estimate excess deaths, based on the current (i.e., 1996) population, for hot and cool summers, using examples of summer conditions that occurred during the 17-year study period. We then calculated expected excess deaths based on the 1996 population of metropolitan Toronto, combining the populations of all six census subdivisions mentioned previously. The summers selected were 1988 and 1995 for hot summers and 1982 and 1992 for cool summers. The number of days in each AT and humidex category and the corresponding mortality rates for each age group were averaged for the two hot and two cool summers. Expected deaths were calculated as follows:

$$D_E = \sum_{i=1}^{n} Pop_{1996}(N_i)R_i, \qquad [5]$$

where D_E = expected number of deaths in a given summer, Pop_{1996} = the 1996 population (either all ages, < 65, or ≥ 65), N = number of days in a heat stress index category, R = the mean mortality rate for a given group in a heat stress index category, and i refers to the humidex or AT category (n = 1–6). The values for each category are summed to yield the number of expected deaths for a given summer. Excess deaths (or, for cool summers, fewer than expected deaths) are the difference between estimated mean, or baseline, summer deaths for the whole study period and those estimated for the summer conditions of interest.

Results

All months between May and September for the 1980–1996 study period had slightly higher minimum and mean temperatures than the 30-year climate normals (1961–1990). The mean daily maximum temperature and the extreme maximum temperature, however, were marginally lower in the study period than in the 30-year period (6).

Humidex and apparent temperature are nearly perfectly correlated and can be readily interchanged as follows (R^2 = 0.9917):

$$\text{Humidex} = 1.138\text{AT} - 1.209. \qquad [6]$$

Most of the days between 1 May and 30 September fell into the lowest humidex (73.7%) or AT (70.9%) category (Table 2).

The second largest percentage fell into the 30–39.9°C humidex and 26.7–32.1°C AT categories. Subdivision of the 30–39.9°C humidex category showed that about twice as many days (16.6%) occurred in the 30–34.9°C portion as in the 35–39.9°C portion (8.2%). Slightly more than 8% of the study period days fell into the third AT category (32.2–40.6°C). Under 2% of the days fell into the 40–45°C humidex range, the level at which TPH would initiate the first stage of its heat wave response. During the study period, 5 summers had no days falling into this category, whereas in 1988, 8 days had a maximum humidex in this range (Table 2).

Only 2 days during the entire 17-year study period had humidex levels above 45°C

Table 2. Heat stress days in Toronto according to humidex and apparent temperature categories.

Range (°F)	Range (°C)	No. of days in period (%)	Mean days/year, 1980–1996	Minimum days/year (maximum days/year)
Humidex (including subdivided categories)				
< 86	< 30	1,918 (73.7)	112.8	93 days in 1991 (133 days in 1992)
86–103.9	30–39.9	645 (24.8)	37.9	19 days in 1992 (57 days in 1991)
104–113	40–45	36 (1.4)	2.2	0 days in 1984, 1985, 1989, 1990, 1996 (8 days in 1988)
> 113	> 45	2 (0.1)	0.1	0 days except 1990 & 1995 (1 day in 1990 &1995)
> 129.2	> 54	0	0	—
86–94.8	30–34.9	432 (16.6)	25.4	14 days in 1982 (37 days in 1991)
94.9–103.9	35–39.9	213 (8.2)	12.5	4 days in 1992 (23 days in 1983)
Apparent temperature				
< 80	< 26.7	1,845 (70.9)	108.5	87 days in 1991 (132 days in 1992)
80–90	26.7–32.1	542 (20.8)	31.6	19 days in 1982 (48 days in 1991)
90.1–105	32.2–40.6	212 (8.2)	12.5	3 days in 1992 (26 days in 1988)
105.1–130	40.7–54.4	2 (0.1)	0.1	0 days except 1990 & 1995 (1 day in 1990 & 1995)
> 130	> 54.4	0	0	—

Table 3. Mortality rates[a] and mean raw deaths by humidex categories (with 30–40°C subdivided).[b]

Mortality group	All days (n = 2,601)	< 30 (n = 1,918)	30–34.9 (n = 432)	35–39.9 (n = 213)	40–45 (n = 36)	45.1–54 (n = 2)
All ages						
Rate μ	1.81	1.79*	1.84*	1.87*	1.96*	2.25*
(σ)	(0.29)	(0.29)	(0.29)	(0.30)	(0.30)	(0.01)
Raw μ	40.42	39.99	41.27	41.82	43.92	52
(σ)	(6.68)	(6.61)	(6.70)	(6.78)	(6.72)	(1.41)
≥ 65 Years (elderly)						
Rate μ	11.31	11.21*	11.41	11.82*	12.44*	13.83
(σ)	(2.18)	(2.14)	(2.18)	(2.34)	(2.73)	(2.44)
Raw μ	30.25	29.94	30.65	31.6	33.44	41
(σ)	(6.07)	(5.96)	(6.3)	(6.08)	(6.77)	(4.24)
< 65 Years (nonelderly)						
Rate μ	0.52	0.51	0.54*	0.52	0.53	0.54
(σ)	(0.17)	(0.17)	(0.17)	(0.16)	(0.15)	(0.27)
Raw μ	10.17	10.06	10.62	10.22	10.47	11
(σ)	(3.24)	(3.23)	(3.37)	(3.05)	(2.89)	(5.66)

[a]Rates are per 100,000 persons in the corresponding age group. [b]Humidex categories > 54°C have 0 days and are omitted from table. H$_0$: Category mean ≠ period mean (μ). *p < 0.01.

(4 July 1990 and 14 July 1995), which would have qualified them as a heat emergency according to Toronto's interim plan (Table 2). The same two days fell into the fourth AT category. These days composed a mere 0.1% of the study period. No days during the study period fell into the highest humidex (> 54°C) or AT (> 54.4°C) categories (Table 2).

Heat stress sensitivity by age group. We observed few notable differences among humidex or AT categories for nonelderly (< 65 years) mortality rates. Mortality rates for the < 65 age group, however, were slightly below the mean for the first humidex ($p = 0.068$) and AT ($p = 0.096$) categories and were significantly higher ($p < 0.05$) for the 30–34.9°C humidex and 26.7–32.1°C AT categories (Tables 3 and 4). Mortality rate disparities among heat stress index categories were greater among the all-ages and elderly (≥ 65) populations. For the lowest humidex and AT categories, mortality rates were below the period mean for the all-ages and the elderly age groups and then rose steadily as both heat stress indexes increased (Tables 3 and 4).

Mortality rates were significantly higher ($p < 0.05$) than the period mean for the second (30–34°C) through fifth (45.1–54°C) humidex categories for the all-ages group, corresponding to an average of 41.27, 41.82, 43.92, and 52 deaths per day for each category (Tables 3 and 4). For the ≥ 65 age group, however, only humidex categories 3 (35–39°C) and 4 (40–45°C) had mortality rates significantly higher than the period mean. These rates correspond to mean elderly deaths per day of 31.6 and 33.44 (Table 3). The results for AT were slightly different. Neither all-ages nor elderly mortality rates were significantly above the mean until the third AT category (i.e., when AT exceeded 32.1°C; Tables 3 and 4). Based on Equation 6, this value corresponds to a humidex of 35.3°C.

The public health impact of heat stress. For the study period, the mean number of daily deaths for the total population was 40.4 and for the ≥ 65 age group was 30.2. An average of 3.5 [95% confidence interval (CI), 1.2–5.8] excess total deaths and 3.2 (95% CI, 0.9–5.5) elderly (≥ 65) deaths

occurred per day for humidex values in the 40–45°C range. These values account for increases above baseline levels of 8.7 ± 3.0% for all ages and 10.6 ± 7.6% for ≥ 65 years. On the 2 days when the humidex exceeded 45°C, excess deaths of 10.6 (total) and 13.8 (≥ 65) were noted for the 1990 occurrence and of 12.6 (total) and 7.8 (≥ 65) for the 1995 occurrence.

If mean mortality rates for each humidex category are calculated for the study period as indicated in Equation 5, 6,586 total and 5,532 elderly deaths would be expected during a typical summer, based on a 1996 population. Estimated total deaths differ slightly with use of mean mortality rates for AT categories, but the values are similar (Tables 5 and 6). The estimated values from both the humidex and AT categoric mean mortality rates are higher than the actual mean number of all ages (6,184) and elderly (4,628) deaths for the 1980–1996 study period because the estimated deaths reflect larger 1996 populations. Because mortality rates for the < 65 age group did not increase with increasing humidex or AT categories, we did not include this group in our estimates.

To illustrate the size of the contribution of humidex or AT levels to excess mortality in a typical summer, excess mortality and 95% CIs for each category are shown graphically. The number of estimated excess summer deaths was below baseline for the first humidex and AT categories (hum1, AT1) for both age groups (Figure 1), reflecting the benign effect of these cooler weather conditions. Despite elevated mortality rates associated with increasing heat stress categories, fewer days in a given summer fall into the higher humidex (hum2–hum5) or AT (AT2–AT4) categories. Thus the contribution of these conditions in mortality totals each summer is relatively minimal. Our estimates show that humidex categories 2–5 each, on average, contribute between 1 and 21 excess deaths per summer, while AT categories 2–4 each contribute between 1 and 29 excess deaths, depending on the age group (Figure 1). The lowest end of the 95% CI for estimated excess deaths was above baseline (zero) for both age groups for humidex categories 3 and 4 and for AT category 3. Due to the small number of days in humidex category 5 and AT category 4, the number of excess deaths was not significantly above zero for the elderly group and was narrowly above zero for the all ages group (Figure 1). However, the largest number of excess daily deaths occurred when these heat stress conditions were present. No days fell into humidex category 6 or AT categories 5 or 6, so the expected deaths for these categories would be zero.

The combined effects of different humidex levels for cool and hot summers for

Table 4. Mortality rates[a] and mean raw deaths by apparent temperature categories.[b]

Mortality group	All days ($n = 2,601$)	< 26.7 ($n = 1,845$)	26.7–32.1 ($n = 542$)	32.2–40.6 ($n = 212$)	40.7–54.4 ($n = 2$)
All ages					
Rate μ	1.81	1.79*	1.83	1.89*	2.25*
(σ)	(0.29)	(0.29)	(0.29)	(0.30)	(0.01)
Raw μ	40.42	40.04	40.94	42.23	52
(σ)	(6.68)	(6.63)	(6.65)	(6.76)	(1.41)
≥ 65 years (elderly)					
Rate μ	11.31	11.23*	11.3	12.04*	13.83
(σ)	(2.18)	(2.13)	(2.18)	(2.44)	(2.44)
Raw μ	30.25	29.97	30.42	32.09	41
(σ)	(6.07)	(5.99)	(6.15)	(6.22)	(4.24)
< 65 years (nonelderly)					
Rate μ	0.52	0.51	0.54*	0.52	0.54
(σ)	(0.17)	(0.17)	(0.17)	(0.15)	(0.27)
Raw μ	10.17	10.07	10.53	10.14	11
(σ)	(3.24)	(3.25)	(3.29)	(2.98)	(5.66)

[a]Rates are per 100,000 persons in the corresponding age group. [b]Apparent temperature categories > 54.4°C have 0 days and are omitted from table. H_0: Category mean ≠ period mean (μ). *$p < 0.01$.

Table 5. Estimated number of total and elderly deaths[a] for a typical summer by humidex categories.

Mortality group	All days[b] ($n = 2,601$)	< 30 ($n = 1,918$)	30–34.9 ($n = 432$)	35–39.9 ($n = 213$)	40–45 ($n = 36$)	45.1–54 ($n = 2$)
All ages	6,586	4,810	1,116	557	98	5
≥ 65 years	5,532	4,045	927	472	84	4

[a]Death estimates based on 1996 populations for each age group (5). All values rounded to nearest whole number. Typical summer based on mean number of days in each category for the period 1980-1996. [b]Estimated "all days" deaths differ between humidex and apparent temperature category totals because of rounding differences in calculated rates.

Table 6. Estimated number of total and elderly deaths[a] for a typical summer by apparent temperature categories.

Mortality group	All days[b] ($n = 2,601$)	<26.7 ($n = 1,845$)	26.8–32.2 ($n = 542$)	32.3–40.6 ($n = 212$)	40.7–54.4 ($n = 2$)
All ages	6,590	4,633	1,389	563	5
≥ 65 years	5,535	3,897	1,153	481	4

[a]Death estimates based on 1996 populations for each age group (5). All values rounded to nearest whole number. Typical summer based on mean number of days in each category for the period 1980-1996. [b]Estimated "all days" deaths differ between humidex and apparent temperature category totals because of rounding differences in calculated rates.

the all-ages group ranged from 34 deaths fewer than baseline levels (26 fewer for ≥ 65 years) for a cool summer to 32 deaths above baseline (27 for ≥ 65 years) for a hot summer. Values were slightly less extreme for AT categories (Table 7). Thus the contribution of the range of weather conditions experienced in Toronto between 1980 and 1996 amounts to less than one-half of 1% above or below mean total summer deaths, and only slightly above this percentage for elderly deaths.

Discussion

Sensitivity to heat stress in Toronto. The Toronto population is highly sensitive to high humidex levels when they occur. On the 2 days during the study period when the humidex exceeded 45°C, deaths increased above baseline levels by nearly 29% for the total population and by close to 36% for the elderly age group. Exposure to these conditions, however, is relatively rare. In any given summer, the actual number of excess deaths associated with hot and humid conditions is relatively low in Toronto. The main reason is

that most days in a Toronto summer (even particularly hot summers such as 1988 and 1995) fall into the first humidex or AT categories, which on average have below baseline numbers of deaths per day. The low numbers of excess deaths are a factor of exposure rather than of vulnerability. In other words, Toronto's population demonstrates increased mortality during high humidex levels, but these weather conditions occur infrequently in Toronto, so exposure to these conditions under current climatic conditions is minimal. In the event of a warming climate, however, more days with dangerously high humidex levels are likely to occur. Given the high sensitivity to hot and humid conditions we have noted for Toronto, we expect the number of deaths to increase if the climate warms.

It is notable that mortality rates increased above the period mean beginning with the second humidex category (30–34.9°C), although the increase in mortality rates was not statistically significant (at $p < 0.05$) for the elderly population until the third category (35–39.9°C). Also, although the highest

mortality rate for the ≥ 65 age group occurred in the > 45°C category, it was not statistically significant (Table 4). Most likely the lack of statistical significance stems from instability caused by the small number of deaths in the ≥ 65 group as well as the low number of days (2) in this humidex category rather than from lower risk in the elderly than all-ages group. In fact, most of the excess deaths associated with increasing humidex occurred among the elderly population. On average, deaths among the ≥ 65 population comprise about 75% of total deaths in Toronto. With increasing humidex (or AT) categories, this percentage steadily increased to nearly 79% of the total, illustrating the heightened susceptibility of older persons to heat stress. This finding corresponds with other studies that have shown the elderly to be at particularly high risk (*10–14*). Thus, it is imperative that heat response actions be directed at the elderly population as well as other high-risk groups, such as persons who are chronically or mentally ill or physically impaired. We have not considered morbidity here, but past research has demonstrated that the number of Toronto's hospital admissions, as well as the number of deaths, increases during hot and humid summer conditions (*9*).

Evaluation of Toronto's interim hot weather response plan. This study has shown that, on average, Toronto experiences 2 days each summer with a humidex in the 40–45°C range, which, under its original interim plan, would be considered heat warning days and thus would warrant the first level of response. Toronto has since revised its interim plan to require 2 consecutive days with a humidex above 40°C before issuing a heat warning (*25*). For the 1980–1996 study period, this would reduce the number of heat warnings from 36 to 8, or about one warning every other summer. Our examination of mortality data for the study period suggests that mean mortality rates on the second consecutive day with a humidex above 40°C were not significantly different from mean death rates on the first day with this humidex level (results not shown). In fact, for the ≥ 65 age group, mean daily mortality rates were actually slightly lower on the second consecutive 40°C day than on the first day (33.22 and 34.03/100,000 elderly). Thus, waiting another day to issue a heat emergency could jeopardize the health of the Toronto population, particularly its elderly residents.

Both the 1999 interim plan and the revised 2000 plan would initiate a heat emergency if humidex levels exceed 45°C. Rarely do conditions reach these levels in Toronto. If summers do not warm above 1980–1996 conditions, a heat emergency is likely to be called in Toronto about once every 7 years.
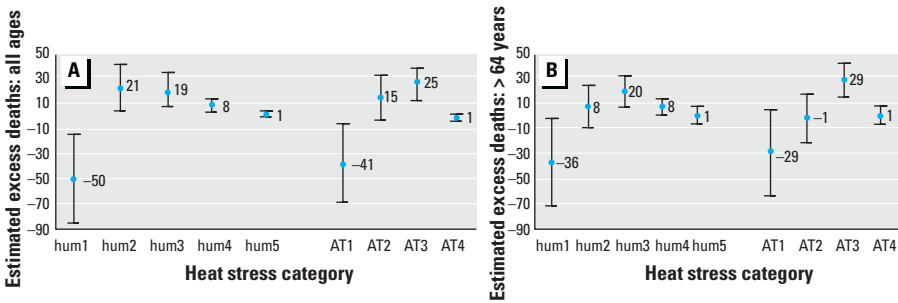

Figure 1. Number of estimated excess deaths and 95% CIs for humidex and apparent temperature categories for (*A*) all ages and (*B*) > 64 years age groups. Values given are for a typical summer, based on mean mortality rates for each humidex or apparent temperature category for the summers of 1980–1996. Abbreviations: AT1, apparent temperature < 26.7°C; AT2, apparent temperature of 26.7–32.1°C; AT3, apparent temperature of 32.2–40.6°C; AT4, apparent temperature of 40.7 to 54.4°C; hum1, humidex < 30°C; hum2, humidex of 30–34.9°C; hum3, humidex of 35–39.9°C; hum4, humidex of 40–45°C; hum5, humidex > 45.1°C.

Table 7. Estimated excess deaths associated with heat stress events for hotter and cooler than average summers.

Range (°F)	Range (°C)	No. days in cool summer	No. days in hot summer	Estimated excess deaths Cool summer all ages (> 64)	Estimated excess deaths Hot summer all ages (> 64)
Humidex (including subdivided categories)					
< 86	< 30	132	101	−58 (−43)	−44 (−33)
86–94.8	30–34.9	14.5	29	12 (4)	25 (9)
94.9–103.9	35–39.9	5.5	17	8 (9)	26 (27)
104–113	40–45	1	5.5	4 (4)	20 (20)
>113	45.1–54	0	0.5	0 (0)	5 (4)
>129.2	> 54	0	0	0 (0)	0 (0)
Total estimated excess deaths				−34 (−26)	32 (27)
Total estimated deaths in an average summer				6,586 (5,532)[a]	
Apparent temperature					
< 80	<26.7	129.5	95.5	−49 (−34)	−36 (−25)
80–90	26.7–32.1	18.5	35.5	9 (−1)	17 (−2)
90.1–105	32.3–40.6	5	21.5	10 (12)	43 (50)
105.1–130	40.7–5 4.4	0	0.5	0 (0)	5 (4)
> 130	>54.4	0	0	0 (0)	0 (0)
Total estimated excess deaths				−30 (−23)	29 (27)
Total estimated deaths in an average summer				6,591 (5,536)[a]	

[a]Values in parentheses are for population > 64 years; values are rounded to the nearest whole number.

Heat emergencies would be rare and unusual events and thus more likely to be taken seriously. In addition, implementation costs would be incurred only infrequently.

For both the total and elderly populations, we observed excess mortality at humidex values below those established for the first-level hot weather public health response (40°C). In a hot summer, an estimated 20 excess deaths would occur in the 40–45°C humidex category and 5 in the > 45°C category (Table 5), which correspond to the first and second stages of Toronto's 1999 interim hot weather response plan. If the response plan had a 100% success rate, it could save an estimated 25 lives in a hot summer and 4 in a cool one. But comparable numbers of excess deaths are noted at lower humidex levels as well. Humidex levels of 30–34.9°C in a hot summer would result in 25 excess deaths, and those of 35–39.9°C would lead to an estimated 26 excess deaths. Thus, by waiting until 40°C to initiate a hot weather response, the interim plan does not address humidex levels associated with 51 excess deaths. Under the modified response plan requiring 2 consecutive days with a humidex above 40°C, the number of excess deaths would be even higher.

In summer 2001, Toronto implemented an air mass-based watch warning system to be used instead of the interim plans outlined here (24,31). This plan, which does not rely on arbitrary cut-off points of humidex or apparent temperature, may be a more appropriate method for deciding when to initiate a heat response than the current plan using 40°C and 45°C.

In addition to communication of heat-related health risk, uptake of preventive measures among high-risk groups is a key factor influencing their success. For example, although elderly persons may know that their age group is more vulnerable to extreme heat and cold, they still may not consider themselves to be at elevated risk. In a study of heat-related mortality in St. Louis, Missouri, senior residents frequently expressed sentiments such as "I've lived here all my life and I never needed air conditioning before, so why should I now?" and "I have an air conditioner but it is too expensive to run, so I'll only use it if conditions become unbearable" (13). In places such as Toronto, where heat waves are less frequent, it is uncertain how elderly and other high-risk groups perceive their vulnerability to heat stress and to what extent they are willing to take preventive action. Public health efforts, especially the education and awareness component, need to take this factor into consideration.

Heat stress indexes and health outcomes. Our results suggest that the comfort levels associated with the humidex classification scheme (Table 1) do not correctly describe health impacts observed in Toronto between 1980 and 1996. We observed excess mortality in the 30–39°C humidex range, which corresponds to "some discomfort." This seemingly innocuous description obscures the fact that during a typical summer, an average of 41 excess deaths occur at the 30–34°C range and close to 42 at the 35–39°C range. It is not until the > 45°C level that the table lists this humidex as dangerous. We have demonstrated that dangerous conditions occur at much lower humidex levels. Although we did not analyze nonfatal health effects in this study, previous research on hot weather morbidity suggests that morbidity patterns are likely to echo mortality patterns (33,34).

The health outcomes accorded to different levels of AT are more appropriate than the comfort levels ascribed to humidex. Even relatively low AT levels of 26.7–32.2°C (80–90°F) are attributed to "fatigue possible with prolonged exposure and/or physical activity" (Table 1). At the 32.3–40.5°C (90–105°F) level, where mortality rates in Toronto first increase, the AT table (Table 1) cautions that "sunstroke, heat cramps, and heat exhaustion [are] possible with prolonged exposure and/or physical activity." The humidex table could be changed to incorporate actual health outcomes observed among urban Canadian populations. The regression equation developed here (Equation 6) can be used to translate health impacts for each AT category to their corresponding humidex levels for use in Canada.

In summary, mortality rates for total and elderly (> 64 years of age) groups increased across humidex and AT categories, with no significant increase for the population < 65 years. Excess mortality was first noted at the 35–40°C humidex range, which is below the 40°C used in Toronto Public Health's 1999 interim hot weather response plan. As Toronto's population continues to age and to grow in size, the number of susceptible individuals will increase regardless of whether the area experiences warming. In the event of a warming climate, more days with dangerously high humidex levels are likely to occur, and along with them, the number of deaths is expected to increase. A combination of hot weather watch/warning systems, well-organized heat emergency response plans, and ongoing education about heat stress precautions is likely to be useful in reducing the harmful health impacts of heat stress conditions. Toronto's hot weather response plan is also an important early step for adaptation to climate change.

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