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ORIGINAL ARTICLE

Monitoring of all-cause mortality in Belgium (Be-MOMO): a new and automated system for the early detection and quantification of the mortality impact of public health events

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Abstract

Objectives Be-MOMO is the monitoring of all-cause death registry data in Belgium. The new methods are described and the detection and quantification of outbreaks is presented for the period April 2006–March 2007. Sensitivity, specificity and timeliness are illustrated by means of a temporal comparison with known health events.

Methods Relevant events are identified from important mortality risks: climate, air pollution and influenza. Baselines and thresholds for deaths by gender, age group, day and week are estimated by the method of Farrington et al. (J R Stat Soc Ser A, 159:547–563, 1996). By adding seasonal terms to the basic model, a complete 5-year reference period can be used, while a reduction of noise allows the application to daily counts.

Results Ignoring two false positives, all flags could be classified into five distinct outbreaks, coinciding with four heat periods and an influenza epidemic. Negative deviations from expected mortality in autumn and winter might reflect a displacement of mortality by the heat waves. Still, significant positive excess was found during five influenza weeks. Correcting for the delay in registration of deaths, outbreaks could be detected as soon as 1–2 weeks after the event.

Conclusion The sensitivity of Be-MOMO to different health threats suggests its potential usefulness in early warning: mortality thresholds and baselines might serve as rapid tools for detecting and quantifying outbreaks, crucial for public health decision-making and evaluation of measures.

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Introduction

In Europe, the importance of real-time mortality monitoring has only been recognized since the heat waves during August 2003. The 3 years needed to estimate the impact at the European level, around 70,000 additional deaths (Robine et al. 2008), demonstrated the lack of functional surveillance systems. Different public health issues have highlighted the need for high-quality early warning: first, the expected increase in extreme weather events due to climate change (Brucker 2005; Haines et al. 2006), second, the potential of infectious and non-infectious diseases to (re-)emerge, and third, the fear of deliberate release of health threatening substances (Mazick 2007). Monitoring of all-cause deaths may be a major source of timely data on progression and impact of health threats, crucial to guide health service response and public health decision-making. Ultimately, it might provide a useful tool for evaluating existing or new measures like influenza vaccination and heat plans.

Reviews of statistical methods for outbreak detection can be found, e.g. in Sonesson and Bock (2003) and Brookmeyer and Stroup (2004), including quality control approaches such as cumulative sums (CUSUM), historical limits, regression models and time series methods such as (seasonal) integrated moving average ((S)ARIMA). Methods are complicated by delays in reporting of deaths, fluctuations in the historical data series due to seasonal cycles, secular trends and outbreaks in the reference data. On the other hand, the algorithm should not be too complex, as stratification will improve event detection and a large number of data series have to be analysed weekly. Several syndromic surveillance systems have been described for infectious diseases (e.g. Stroup et al. 1989; Farrington et al. 1996; Hutwagner et al. 1997), while literature on routinely used real-time mortality monitoring is still limited.

In the US, the Centres for Disease Control and Prevention use the 122 Cities Mortality Reporting System to monitor the weekly total number of deaths, as well as the number due to pneumonia and influenza (Simonsen et al. 1997). In the United Kingdom, the rapid estimates from the Office for National Statistics routine weekly deaths reporting have been shown to provide a quick indication of the excess during the heat wave of 2003, although initial figures were an underestimate (Johnson et al. 2005). The French national institute for public health surveillance (InVS) initiated a pilot network in July 2004, showing the utility of simultaneously monitoring all-cause deaths and hospital emergency data (Josseran et al. 2006). Sweden implemented a system in the beginning of 2005, aiming at a timely detection of outbreaks of deaths by week, age, sex and municipality (Sartorius et al. 2006).

In Belgium, the registration of deaths into the National Register was obliged by law in 1983, although a database based on death certificates already exists since the late sixties. The Scientific Institute of Public Health initiated the weekly surveillance of these data as a reaction to the 2003 impact. While the initial aim was a rapid quantification, mainly focussing on heat-related mortality and daily level data, a gradual decrease in registration delays has finally allowed an exploration of the ultimate aim, i.e. early detection. Because of the expectation that daily and weekly number of deaths might provide complementary information, both levels were considered.

The new Be-MOMO procedure, a modification of the method developed by Farrington et al. (1996), was implemented in December 2007. A website for dissemination of results is currently limited to graphs and a tabulation of excess for flagged days (Be-MOMO 2009), but will be expanded soon. The name Be-MOMO refers to our active partnership in the ongoing European monitoring of excess mortality for public health action (EuroMOMO) project, co-funded by the European Commission and aiming at developing and strengthening real-time mortality monitoring across Europe (Anonymous 2009).

The main requirements of routine surveillance are timeliness, sensitivity and specificity. Sensitivity can be evaluated at the level of case-reporting by the proportion of cases of a health condition detected, and second, on the ability to detect epidemics (Centers for Disease Control and Prevention 2001). Moreover, as a high rate of false alerts may trigger inappropriate investigations, the proportion of outbreaks identified by the system that are true epidemics is needed to assess the positive predictive value. For all-cause mortality, however, the number of relevant events is hard to define; the impact of known events is not certain while other threats might not be known yet.

Be-MOMO output is illustrated through a retrospective application on the 1-year period April 2006–March 2007, including an extremely warm summer and a winter season with influenza A/H3N2. In the absence of an identifiable gold standard, sensitivity, specificity and timeliness are presented by means of a temporal comparison between detected outbreaks and known public health events.

Methods

Data

Each Monday, we receive data on all deaths that were entered into the National Register up till Friday of the week before. The data comprise dates of birth and death, gender, nationality and places of residence and death, but the death causes are unknown. Persons dying abroad are removed from the analyses since they are assumed to be unaffected by threatening conditions in Belgium. It concerns 2–4% of total Belgian mortality (period 2002–2007), with nearly 60% of them also residing outside Belgium. The National Register also provides population registry data, more specifically the sizes at 1 January by gender, age and place of residence.

For recent, incomplete data, final numbers of deaths are estimated by extrapolation of already observed numbers, using the median percentage of data available after the same number of registration days during the previous year (excluding the most recent 6 months). Weekends and national holidays are not counted as registration days. Stratification is only done for age groups as the delay difference between genders can be ignored. Around 95% of data are available after 1 month.

Data on main risk factors allow a rapid screening of potential mortality causes. Daily minimum and maximum temperature measured at the station of Uccle (T_{min} and T_{max}), are obtained from the Royal Meteorological Institute (RMI, http://www.meteo.be/meteo/view/). The Interregional Environment Agency (IRCEL–CELINE, http://www.irceline.be) provides national-level spatial averages of two important indicators of air quality: ambient air concentrations of ground level ozone (O_3, daily maximum of a running 8 h mean) and particulate matter of diameter <10 µm (PM_{10}, 24 h mean). Influenza data considered are the percentage of visits for influenza-like illnesses (ILI) and acute respiratory infections (ARI), collected by the Sentinel General Practitioners (National Influenza Centre, http://www.iph.fgov.be/flu).

Mortality baseline

An extension of the over-dispersed Poisson method developed by Farrington et al. (1996) has been adopted. The original model is quasi-likelihood log-linear and includes a linear time trend, with Y_t representing the observed count at week t and Φ the dispersion parameter:

$$\log(\mu_t) = \alpha + \beta t, \quad E(Y_t) = \mu_t, \quad V(Y_t) = \Phi\mu_t$$

The basic method accounts for seasonal fluctuations by modelling only similar periods in time to t. The reference weeks are specified by the window half-width w and the number of years back b: if the current week is x of year y then weeks $x - w$ to $x + w$ from years $y - b$ to $y - 1$ are used, giving a total of $n = b\,(2w + 1)$ baseline weeks. The model is re-estimated three times: first, to account for outbreaks in reference values by lowering weight of outliers; second, to correct for over-dispersion by rescaling data; and a third time with the parameter β set to zero if the trend is not significant. The first step is crucial because past outbreaks can result in an overestimation of baseline and thresholds and hence reduce sensitivity. Weights $w_t = \gamma s_t^{-2}$ are used for weeks with $s_t > 1$ and $w_t = \gamma$ otherwise, where s_t are the standardized Anscombe residuals and γ is a constant such that $\sum\gamma = n$.

A first limitation of the original method is the restriction on the amount of reference data imposed by the seasonality correction, which might be problematic, e.g. when outbreaks frequently occur around the same time of the year (Brookmeyer and Stroup 2004). The moving window approach also excludes data from the most recent year, although they might improve prediction. Third, estimated baselines have been found to contain considerable random variation when modelling daily deaths.

The original model has therefore been extended by entering seasonal terms: a complete 5-year reference period can be modelled and seasonality is captured by a smoothening sine wave component, reducing noise associated with daily data. With Y_t the observed mortality count on day t, the extended model has the form:

$$\begin{aligned}\log(\mu_t) = \alpha + \beta_1 t + \beta_2 \sin(2\pi t/365) + \beta_3 \cos(2\pi t/365)\\ + \log(\text{pop}_t),\\ E(Y_t) = \mu_t, \quad V(Y_t) = \Phi\mu_t\end{aligned}$$

Observed values Y_{d-2008} to Y_{d-183} are used for predictions for day d. Population sizes are introduced as an offset, i.e. constraining the coefficient to equal one. For retrospective analyses, population sizes are estimated at the level of both day and week by linear interpolation between values on 1 January. A similar model is implemented for weekly death counts, with t representing the week, $\beta_2 \sin(2\pi t/52) + \beta_3 \cos(2\pi t/52)$ the seasonal part, and Y_{w-285} to Y_{w-26} the reference period for week w.

Excess mortality and confidence intervals are calculated by subtracting the expected numbers and their 95% confidence limits from the observed numbers. The confidence limits are estimated using a 2/3-transformation as described for the prediction interval in the next paragraph, with the difference that the dispersion parameter is set to zero to capture only the model variance. Next to the absolute surplus of deaths, the percentage excess above expected values is presented for comparison purposes.

Mortality threshold

The threshold is defined as the upper limit of a $100(1 - \alpha)\%$ prediction interval. It is recommended to account for skewed distributions which might result from low counts, e.g. by normalizing the distribution and transforming the results back to the original scale. The upper prediction limit is calculated by the formula presented in the original method (Farrington et al. 1996), inducing approximate symmetry by a 2/3-power transformation and accounting for over-dispersion. The correction for skewness ensures a constant false positive probability over a broad range of expected values. Mortality counts above the 99.5% upper limit are flagged; the value α was chosen after some experimentation as the best compromise between sensitivity and specificity. The detection of chance events is further reduced by ignoring days flagged in only one subpopulation, i.e. in only one of six specific levels for gender by age group, except if they can be linked to alerts on adjacent days. This rule is not applied for flags from weekly thresholds as they are less prone to random variation.

Performance

The authors have tried to capture relevant events by applying criteria to the risk factors for which an impact is expected. Previous research (Cox et al. 2008b) has shown that excess mortality during summer 2006 was not limited to the two heat waves defined by the RMI definition: at least five consecutive days with a maximum temperature of 25°C or above, including at least three tropical days with a maximum temperature of 30°C (RMI 2008). Therefore, only the first part of this criterion has been adopted, capturing all heat-related outbreaks for 2006. As the current definition for cold wave does not contain information on temperature or duration (RMI 2008), cold is considered to be a 5-day period with T_{min} below zero and at least 3 days with T_{max} below zero. The criterion for air pollution is at least 2 days with concentrations above the European standards of 120 µg/m^3 O_3 and 50 µg/m^3 PM_{10}. The epidemic period for influenza is determined by a threshold of 2% consultations for ILI, while a seasonal threshold is used for ARI (National Influenza Centre, http://www.iph.fgov.be/flu). Also day of the week is presented in outputs, because single-day alerts among persons younger than 65 during weekends might be a reflection of car accidents.

The timeliness of the system is presented by applying current methods to the preliminary data available at the time of the study period. Analyses are implemented in STATA software (version 10) for 12 strata, representing all combinations of gender levels male, female, both and age groups and <65, 65–84, 85+, all ages.

Results

Summarizing mortality from 2003 to 2007, daily number of deaths showed a median of 278 with standard deviation 33.8, and was usually highest in January (median 319, SD 24.2) and lowest in August (median 249, SD 28.7). Around 20% of deaths were younger than 65 years, 50% had age 65–84 and 30% age 85 or more. Daily rates on 100,000 inhabitants were around 0.6, 9 and 45 deaths, respectively.

Figure 1 presents total population mortality, reference lines and potential risk factors for the period under study. Positive deviations from baseline are observed during three large peaks in June–July and a smaller one in September. Mortality was mostly lower than expected the seasons afterwards, except for weekly counts (slightly) above the baseline from week 52 to week 3 and from week 5 to week 10. Except for the period around New Year, all visually detected outbreaks coincide with one of the five main events identified: (1) the heat wave from 09/06 to 13/06 with elevated O_3 from 08/06 to 13/06, (2) the heat from 30/06 to 06/07 with only 1 day with temperature above 30°C and O_3 alerts from 30/06 to 05/07, (3) the severe 21-day heat wave from 10/07 to 30/07 with critical O_3 from 15/07 to 22/07 and 25/07 to 28/07, (4) the late heat from 10/09 to 16/09, and (5) the influenza epidemic from week 5 to 10. No mortality increases were found for the remaining smaller events: a peak in O_3 (17/06–18/06) and three alerts for PM_{10} (16/09–17/09, 15/03–16/03 and 24/03–25/03).

Table 1 shows the strata and risk factors for all alerts generated by weekly and daily thresholds, concerning seven flagged weeks and 26 days. Alerts can be classified into seven distinct potential outbreaks. The first two clusters, week 24 and 27 with, respectively, three and two alert days and weekly flags in many strata, coincide with the first two heat periods. The third outbreak reflects the severe heat wave and contains alert weeks 29 and 30 with five and seven flagged days, respectively. Next, three small clusters limited to daily level alerts can be observed: two alert days coinciding with the late heat in September and two single flagged days in specific subpopulations. The final outbreak falls inside the influenza epidemic and contains five alert days within flagged weeks 6–8.

A quantification of the impact during the heat periods and influenza episode is presented in Table 2 for the elderly (85+) and the total population. While excess number of deaths was highest for the 21-day long heat wave, the percentage excess shows a similar relative impact for the first heat in June: around 30% in the elderly and 19% in the total population. The confidence interval for the excess in September suggests significance only for

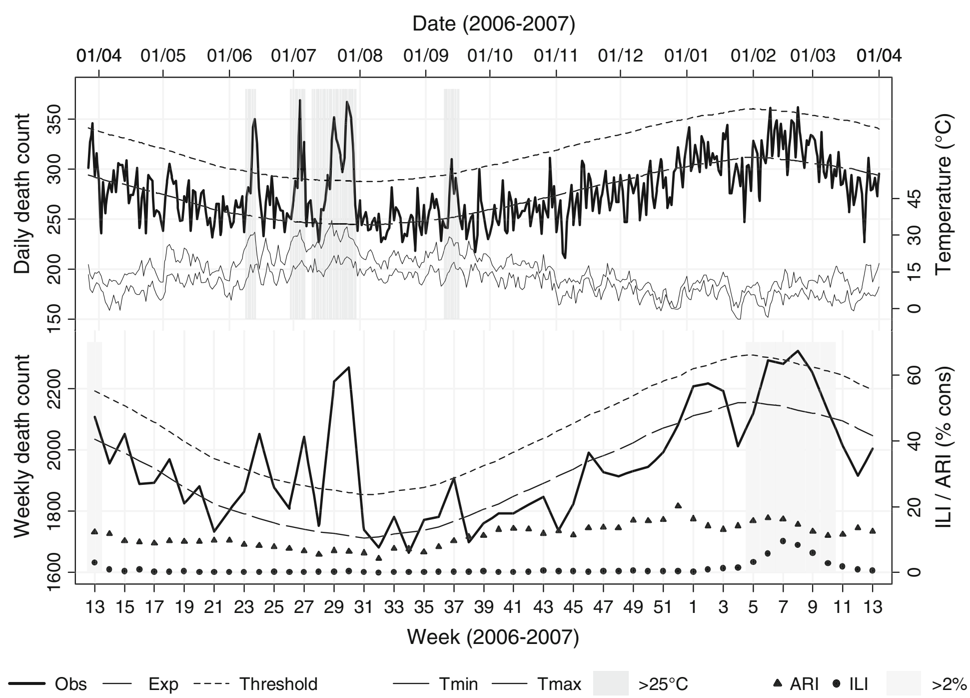

Fig. 1 Total population mortality (Observed, Expected, Threshold) aggregated by day (*upper panel*) and week (*lower panel*), maximum and minimum temperatures and consultations for influenza-like-illnesses and acute respiratory infections, period April 2006–March 2007

Table 1 Be-MOMO report presenting risk factors and gender by age strata (M = males, F = females, T = total) for all daily and weekly alerts retrospectively generated for the period April 2006–March 2007

Event	Date	Age group				Potential risk factors				
		<65	65–84	85+	Total	T_{max}	T_{min}	O_3	PM_{10}	Dow
Heat wave[a] (+O_3)	12/06/06			F T	M F T	**30**	15	**137**	23	Mon
	13/06/06		F T	F T	F T	**31**	18	**150**	35	Tue
	14/06/06				F T	**22**	18	**103**	32	Wed
	Week 24			F T	M F T	ILI 0.3 ARI 7.8				
Heat[b] (+O_3)	04/07/06	M	M T	M F T	M F T	**32**	19	**162**	34	Tue
	06/07/06		T		M F T	**27**	18	101	24	Thu
	Week 27		M T	F T	M F T	ILI 0.3 ARI 5.5				
Heat wave[a] (+O_3)	17/07/06				T	**32**	17	**146**	25	Mon
	19/07/06			F T	M F T	**36**	20	**179**	32	Wed
	20/07/06		T	M F T	M FT	**30**	22	**136**	34	Thu
	21/07/06		F T		F T	**32**	19	**137**	40	**Fri**
	22/07/06			F	F T	**29**	22	**122**	33	**Sat**
	Week 29	T	M F T	M F T	M F T	ILI 0.4 ARI 6.4				
	23/07/06			T	F T	**27**	18	99	31	Sun
	24/07/06			F	F T	**29**	18	106	28	Mon
	25/07/06			F T	F T	**32**	20	**176**	36	Tue
	26/07/06		F T	F T	M F T	**34**	21	**198**	43	Wed
	27/07/06		M F T	F T	M F T	**30**	21	**144**	30	Thu
	28/07/06	T	T	F T	M F T	**29**	20	**126**	34	**Fri**
	29/07/06			F T	F T	**28**	17	108	28	**Sat**
	Week 30		M F T	M F T	M F T	ILI 0.1 ARI 6.0				
Unexplained	06/09/06	F				**27**	15	58	30	Wed
	Week 36					ILI 0.2 ARI 9.7				
Heat[b]	13/09/06				T	**29**	18	93	37	Wed
	15/09/06		M		M	**27**	16	73	43	**Fri**
	Week 37					ILI 0.4 ARI 10.9				
Unexplained	07/10/06		M			16	12	54	17	**Sat**
	Week 40					ILI 0.1 ARI 13.4				
Influenza	09/02/07				M T	7	2	52	24	**Fri**
	Week 6				F	ILI **5.9** ARI **16.7**				
	12/02/07		M		M	11	7	58	13	Mon
	16/02/07				F	16	6	43	17	**Fri**
	Week 7	F				ILI **9.6** ARI **16.3**				
	19/02/07	F				9	5	19	**56**	Mon
	22/02/07				T	12	5	48	22	Thu
	Week 8				F T	ILI **8.4** ARI **14.7**				

Critical levels in bold: $T_{max} > 25°C$, $T_{min} < 0°C$, $O_3 > 120\ \mu g/m^3$, $PM_{10} > 50\ \mu g/m^3$, day of week = Friday, Saturday or Sunday, ILI (influenza-like illnesses) > 2%, ARI (acute respiratory infections) > seasonal threshold

[a] Heat wave (RMI definition)

[b] Heat period (5 days with $T_{max} > 25°C$)

the elderly, with a relative impact more than twice the effect for the total population. Negative estimates for excess are found for the first week with influenza activity and again for the week right after the epidemic. Total population estimates show a significant excess of around 5% in weeks 6–9, with a peak of 7.7% in week 8. The impact in the age group 85+ occurs 1 week later: around 4% in weeks 7 and 10 and around 10% in weeks 8 and 9.

Timeliness is illustrated in Table 3 for the daily alerts generated in the total population. Out of 20 flags, 9 were

Table 2 Observed mortality (Obs), excess number of deaths (Excess) and percentage excess above expected (Perc) in elderly (85+) and total population, heat episodes 2006 and influenza season 2007

Period	Days	85+			Total		
		Obs	Excess (95% CI)	Perc	Obs	Excess (95% CI)	Perc
Summer 2006							
09/06–15/06[a]	7	656	150 (138, 162)	29.6	2,122	352 (330, 374)	19.9
30/06–08/07[b]	9	779	147 (132, 161)	23.2	2,580	357 (329, 384)	16.1
10/07–01/08[a]	23	2,113	505 (467, 542)	31.4	6,751	1,108 (1,039, 1,178)	19.6
10/09–18/09[b]	9	741	91 (77, 106)	14.1	2,389	121 (94, 149)	5.4
June	30	2,328	167 (116, 218)	7.7	8,054	502 (408, 595)	6.6
July	31	2,827	656 (606, 707)	30.2	9,081	1,461 (1,367, 1,555)	19.2
August	31	2,188	19 (−31, 68)	0.9	7,650	34 (−59, 127)	0.4
September	30	2,252	72 (23, 121)	3.3	7,661	73 (−19, 164)	1.0
Influenza 2007							
Week 5	7	658	−33 (−48, −17)	−4.8	2,119	−62 (−89, −36)	−2.8
Week 6	7	707	17 (1, 32)	2.4	2,292	115 (89, 142)	5.3
Week 7	7	718	31 (16, 47)	4.5	2,281	114 (87, 140)	5.2
Week 8	7	752	70 (55, 86)	10.3	2,323	167 (141, 193)	7.7
Week 9	7	742	69 (54, 84)	10.2	2,249	109 (83, 135)	5.1
Week 10	7	694	29 (14, 44)	4.3	2,127	0 (−26, 26)	0.0
Week 11	7	637	−21 (−36, −6)	−3.1	2,013	−97 (−123, −71)	−4.6
Week 5–10[c]	42	4,271	183 (90, 274)	4.5	13,391	443 (285, 600)	3.4

[a] Heat wave (RMI definition) + 2 days afterwards to capture delayed effects

[b] Heat period (5 days with $T_{max} > 25°C$) + 2 days afterwards to capture delayed effects

[c] Epidemic period (ILI > 2%)

already captured by estimates made the next Monday and another 9 the analysis afterwards. An exception is the long period needed for the alert on 17/07, when observed mortality was only slightly above the threshold. It has to be noted that events during the weekend can never generate flags within the first week. Considering the number of outbreaks instead of alerts, all except the severe heat wave could be detected within 1 week after the onset. Data for the second week of this heat wave did, however, also produce flags in less than a week.

Discussion

As in many European countries, efforts towards routine monitoring of deaths were only initiated after the heat impact of summer 2003, and a national heat plan was implemented (Belgian Federal Public Service Health, Food Chain Safety and Environment 2008). Heat-related mortality in Belgium has been described much earlier, however, as for the heat wave of 1994 (Sartor et al. 1995). More recently, the summers of 2003 and 2006 have confirmed the impact, with estimated excess number of deaths around 1,297 (Sartor 2004) and 1,107 (Maes et al. 2007), respectively. Comparisons of estimates are, however, complicated by the use of different methods, age groups, and heat periods for the calculation of excess.

An evaluation of different method types has resulted in the implementation of the log-linear Farrington approach because of statistical considerations such as reporting delays, non-normality, seasonality, trends, previous outbreaks and over-dispersion, but also because of the practical advantage to use a common daily and weekly algorithm in many strata. The epidemic and seasonal correction were found to be the most important model-building steps. The reweighting procedure is more practical than arbitrary manual exclusion of outliers and reduces bias in the threshold values without lowering specificity. The application to daily counts has been made possible by entering seasonal terms in the basic model, which also allowed the extension of reference data to a full 5-year time series including more recent values. While the extra-Poisson variability in some strata appears to be sufficiently captured by the model, the dispersion parameter corrects for remaining residual dispersion in other strata.

One limitation is that the dependence between adjacent baseline values is ignored. Although time series methods are preferred in case of autocorrelation, they often require the use of differencing and transformations for stabilization. This makes model identification complicated and

Table 3 Final deaths and preliminary and estimated numbers illustrating the time to detection for all total population alert days, period April 2006–March 2007

Date	Dow[a]	Obs final[b]	Next Monday			Within 2 weeks			Within 3 weeks			Within 4 weeks		
			Obs[c]	Est[d]	Al[e]	Obs	Est	Al	Obs	Est	Al	Obs	Est	Al
12/06/06	Mon	342	216	346	×	301	349	×	321	341	×	327	340	×
13/06/06	Tue	350	173	331	×	293	347	×	322	347	××	334	348	×
14/06/06	Wed	325	103	289		262	323	×	299	325	×	304	320	×
04/07/06	Tue	369	190	365	×	303	358	×	336	361	×	347	361	×
06/07/06	Thu	327	37	247		218	280		281	309	×	302	317	×
17/07/06	Mon	294	161	256		244	277		268	284		279	289	
19/07/06	Wed	328	47	135		245	300	×	301	327	×	311	326	×
20/07/06	Thu	352	22	147		273	352	×	332	365	×	340	356	×
21/07/06	Fri	329	1	40		239	329	×	294	327	×	309	325	×
22/07/06	Sat	324	0	/		223	314	×	290	325	×	310	327	×
23/07/06	Sun	314	0	/		222	318	×	287	322	×	299	316	×
24/07/06	Mon	297	181	288		261	299	×	281	297	×	284	294	×
25/07/06	Tue	312	170	326	×	271	319	×	294	315	×	299	310	×
26/07/06	Wed	366	153	429	×	312	381	×	342	369	×	347	365	×
27/07/06	Thu	362	51	338	×	302	388	×	335	369	×	344	361	×
28/07/06	Fri	351	5	202		264	363	×	327	363	×	333	351	×
29/07/06	Sat	315	0	/		250	353	×	298	334	×	304	321	×
13/09/06	Wed	309	123	341	×	268	320	×	282	305	×	297	312	×
09/02/07	Fri	361	11	444	×	275	366	×	320	355	×	347	366	×
22/02/07	Thu	362	57	337	×	287	367	×	338	369	×	344	362	×

[a] Day of week

[b] Finally observed number of deaths

[c] Available number of deaths

[d] Estimated number of deaths

[e] Alert generated

highly data specific, hampering the automation for a large number of subpopulations. Moreover, Poisson models are more appropriate than, e.g. the popular (S)ARIMA method when data are not normally distributed, as is the case for low death counts resulting from daily aggregation in specific strata. Although autocorrelation might introduce bias in the thresholds, the advantages of correcting for it do not outweigh other issues, as remaining correlation among residuals was found to be sufficiently low. Another shortcoming is the re-computing of prediction-intervals at every time instance (Höhle et al. 2009). As deviations are not accumulated, sustained shifts become hard to detect and performance might be improved by methods from statistical process control.

Sensitivity of the combined daily and weekly level system can be roughly calculated to range between 56% (5 out of 9) and 100% (5 out of 5), depending on whether the four peaks in air pollution are included. The fact that pollution only lasted for 2 days might explain the absence of alerts: although the impact of elevated air pollution during heat and cold waves has been studied extensively (e.g. Sartor et al. 1995), the public health relevance of very short episodes in the absence of other risks is less certain. The expectation that stratification increases chances at detecting outbreaks in vulnerable subpopulations is confirmed by, e.g. the large numbers of heat-related flags among females older than 85. Similarly, the positive predictive value is approximately 71% (5 out of 7) to 100% (5 out of 5), depending on whether the false positive assumption is applied. The proposed rule has been found to be acceptable. Although the alert among females younger than 65 on 06/09 might be heat-related, temperatures were below 25°C the days before and the heat impact in younger age groups is known to be less important.

Although most monitoring systems focus on weekly mortality data, this study suggests that complementary information might be obtained from daily and weekly alert systems. The hypothesis that weekly death counts are less appropriate for heat-related outbreaks, often implying large excess during a limited number of days, is illustrated by the lack of weekly flags during the heat in September. Although weekly thresholds were able to pick up the other heat periods, sensitivity in specific strata was sometimes not sufficient, e.g. in age group 65–84 during the first heat wave. This is compensated by an increased specificity, illustrated by the absence of false positive weeks.

On the other hand, for longer-term outbreaks with smaller daily excess, as caused by influenza, daily thresholds might not be reached and weekly totals are expected to be more powerful. The noise in daily counts might obscure such increases, as demonstrated by the influenza outbreak which is difficult to detect from daily data in Fig. 1. Though, the influenza impact was also detected by the daily system. The populations flagged by daily and weekly thresholds, however, do not correspond, motivating the potential complementariness. Sensitivity could be further increased by considering cumulative excess or other methods that accumulate information, as already mentioned above. This might also improve sensitivity in small populations, possibly allowing further stratification by, e.g. age or region. A spatially stratified mortality alert system has been described for Sweden (Sartorius et al. 2006), but also more complex spatiotemporal methods such as scan statistics might be considered.

Estimated excess for summer 2006 is higher than previously reported estimates (Maes et al. 2007). However, the baseline used by the previous study was probably overestimated as the general decrease in mortality rates in the reference years 2001–2005 was not taken into account. The fact that significant increases in mortality were also observed outside the heat waves defined by the RMI indicates that analyses of excess mortality should not be restricted to these official heat waves. Evidence exists that the observed shortage in mortality during following autumn and winter might indicate a harvesting effect, i.e. a short-term displacement of deaths by the heat waves (Pattenden et al. 2003; Hajat et al. 2006). This hypothesis is supported by the fact that weeks 40–52 of 2006 had the lowest mortality observed in available time series (1985–2008): a total of 24,592 deaths (weekly rate = 17.9/100,000 inhabitants) compared to a median of 26,631 (SD 1,331) for the remaining 23 years, with a minimum of 25,204 (rate = 19.1) in 1996 and a maximum of 30,294 (rate = 23.4) in 1989. Secondly, validity of the baseline is confirmed by the shortage in deaths reported by a previous study, showing similar excess estimates for weeks 6–10 obtained by SARIMA modelling (Maes et al. 2008).

While the lack of timely data is often a hampering factor for mortality surveillance, most alerts in this study were already generated within 1–2 weeks after the event, depending on the number of registration days included. Considering the main five outbreaks, only the long heat wave could not yet be detected from estimates made at the next analyses. Although the onset was on a Monday, the higher death counts appeared only later that week. In general, while a moderate excess on, e.g. Monday or Tuesday might be detected within 1 week, proportion of data available for, e.g. Thursday or Friday is often too low to make reliable estimates. In case of high excess, however, also events near the end of the week can sometimes be captured already at the following analyses. As a gradual decrease in registration delays can be observed, the time to detection will only improve. While timeliness of alerts might allow immediate public health interventions in case of slow longer-term outbreaks, time to detection for acute outbreaks as observed for short heat periods is probably not short enough for a timely reaction. An optimal timeliness would be obtained through a web based process of death declaration by a certifying physician.

Also the prospective implementation of the monitoring system has confirmed its performance. Most outbreaks could be attributed to specific health events, often heat or cold snaps, while an absence of influenza-related alerts for season 2007–2008 was in agreement with a low activity of virus types B and A/H1N1 (Cox et al. 2008a). Causality was less obvious for an outbreak around New Year 2007, as a combination of relevant events was identified: a cold spell with critical PM_{10} levels and ARI above the seasonal threshold. Even in the absence of such events, Christmas/New Year's holidays are known to be a risk factor for mortality, though the causes of this phenomenon are not well understood (Phillips et al. 2004; Milne 2005). The investigation of specific causal associations is a next challenge for Be-MOMO, as appropriate modelling of well-chosen risk variables is required (Dominici et al. 2002), while correcting for confounding by other factors (Braga et al. 2000; O'Neill et al. 2005).

The sensitivity of the Be-MOMO system to different types of health threats suggests that, when properly used, it might be a useful tool for early warning. All-cause mortality is a very powerful health indicator and total coverage of cases is achieved. Although using registry data, the time to detection is within 1–2 weeks, allowing a quick reaction from public health authorities when needed. The identification of heat-related excess outside the official definition suggests reconsidering the heat wave scenario, while the observed influenza-related mortality might trigger actions for higher vaccination coverage.

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