Published by Oxford University Press on behalf of the International Epidemiological Association
International Journal of Epidemiology 2013;**42**:1164–1176

doi:10.1093/ije/dyt115

Visualizing Europe's demographic scars with coplots and contour plots

Jonathan Minton,[1]* Laura Vanderbloemen[2] and Danny Dorling[3]

[1]Department of Urban Studies, University of Glasgow, Glasgow, UK, [2]Department of Health Science, University of York, York, UK and [3]School of Geography and the Environment, University of Oxford, Oxford, UK

*Corresponding author. Department of Urban Studies, University of Glasgow, 25 Bute Gardens, Glasgow, G12 8RS. E-mail: nate.minton@gmail.com

Accepted 21 May 2013

We present two enhancements to existing methods for visualizing vital statistics data. Data from the Human Mortality Database were used and vital statistics from England and Wales are used for illustration. The simpler of these methods involves coplotting mean age of death with its variance, and the more complex of these methods is to present data as a contour plot. The coplot method shows the effect of the 20th century's epidemiological transitions. The contour plot method allows more complex and subtle age, period and cohort effects to be seen.

The contour plot shows the effects of broad improvements in public health over the 20th century, including vast reductions in rates of childhood mortality, reduced baseline mortality risks during adulthood and the postponement of higher mortality risks to older ages. They also show the effects of the two world wars and the 1918 influenza pandemic on men of fighting age, women and children. The contour plots also show a cohort effect for people born around 1918, suggesting a possible epigenetic effect of parental exposure to the pandemic which shortened the cohort's lifespan and which has so far received little attention.

Although this article focuses on data from England and Wales, the associated online appendices contain equivalent visualizations for almost 50 series of data available on the Human Mortality Database. We expect that further analyses of these visualizations will reveal further insights into global public health.

Keywords Demography, visualisation, mortality, epidemiological transition, vital statistics, public health

Introduction

Accurate records of births and deaths have been collected by some nations for centuries. Their value in understanding long-term trends in population health has long been recognized by epidemiologists and actuaries alike, allowing researchers to identify important changes in mortality since the late 19th century by helping identify otherwise hidden patterns.[1–6] High-quality vital statistics make possible the exploration of: age effects, of the type identified by Gompertz; cohort effects, of the type identified by Kermack among others, and those currently associated with Barker's foetal origins hypothesis; and period effects, such as the 20th century 'epidemiological transition'.[7–11]

In this paper, we present two enhancements to established visual methods for exploring vital statistics. The simpler enhancement is to coplot mean age of death, a summary measure of central tendency, alongside its variance, a measure of deviation. The more complex of these methods involves converting age- and period-specific mortality rates into contour plots, topographical representations similar to Lexis plots. These measures, unlike life expectancies which involve some element of statistical projection, are purely empirical. Exploring these contour plots allows age, period and cohort effects to be identified simultaneously. They show a cohort effect associated with the 1918 influenza pandemic which has, to our knowledge, received little attention in the demographic and epidemiological literature to date, and has not previously been visualized as clearly as in these new demographic maps.

Methods

Data used

Data were taken from the Human Mortality Database which presented the number of births and deaths, for males and females separately, for all years for which data are available, and for every single year of age band from 0 to over 100 years inclusive, and partially imputed by the Human Mortality Database for persons aged 80 years and over.[12] Because of small sample sizes at the older age groups, the contour plots used data up to the age of 80 years inclusive.

As the Human Mortality Database is a collection of vital statistic data, the total number of observations involved in the analyses is huge.[13] For some nations the records go back for just a few years whereas for others records go back to the 17th century. Results from England and Wales are used mainly for illustration within this article, and results from many other developed world nations are presented in the Supplementary Appendix (available as Supplementary data at *IJE* online).

Calculation of metrics

Age-, country-, gender- and date-specific crude mortality rates were calculated by dividing the number of deaths at each age by the number of persons alive at that age. Arithmetical means and variances of ages of death were calculated for each country, gender and year; the formulae used were:

$$\bar{x} = \sum \frac{fx}{n} \text{ for the mean and}$$

$$\sigma^2 = \frac{\sum fx^2}{n} - \bar{x}^2 \text{ for the variance,}$$

where x refers to age of death, f to the frequency of observations at that age and n to the total number of deaths observed for that country, gender and year combination. Variance around the age of death was calculated both including and excluding deaths of persons aged under 5 years to account for the effects of child mortality. These results are presented for England and Wales within the main results below. Equivalent results are presented for other nations in the Supplementary Appendix (available as Supplementary data at *IJE* online).

Contour map representations

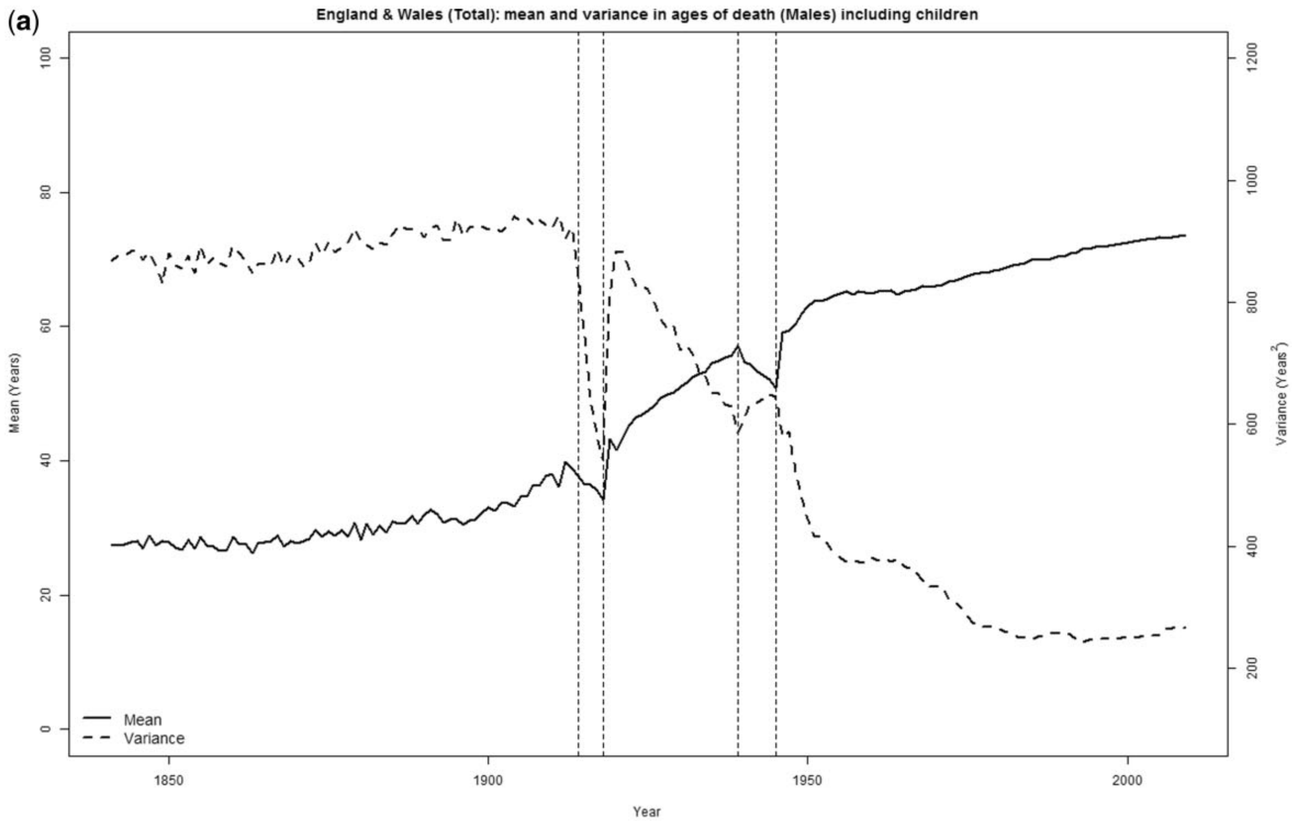
The crude mortality rates produced are each effectively a discrete two-dimensional array of numbers, one dimension representing a year of human age, the other representing a temporal year. Contour plots draw a continuous interpolated topology of these arrays, linking together spaces estimated to have equal values with monotone lines (the contours). They are commonly used in geographical topographical maps, where each contour represents a given height. On a topographical map, therefore, a series of concentric circles would represent either a hill, if the central contour were of a higher value than surrounding contours, or a depression, if the central contour were lower than surrounding contours. Steeper inclines are indicated by the contours being bunched closer together, and where the gradient is shallower the contours are further apart. These plots are similar to Lexis plots, except that these plots link points of equal value that have been interpolated as based on the data, whereas in general Lexis plots do not.[14] Contour plots were produced using the Lattice package within the R statistical programming environment, and coloured so that white represents a very low mortality rate, and darker shades indicate higher mortality rates.[15,16]

Results

Mean and variance plots

Figure 1 shows the mean/variance plots for England and Wales between 1841 and 2005. Dashed vertical lines have been added for the years 1914, 1918, 1939 and 1945 to indicate the start and end of the World Wars. When deaths at all ages are considered (see also Figure 1a and c), we see that the mean ages of death increased rapidly during the first half of the 20th century. Afterwards, the rate of increase began to taper off. It is not clear if levels are levelling off to an asymptote or continuing to increase more gradually. Over this same time period, the variance in the mean ages of death at each time period has decreased. The two metrics are strongly inversely correlated (Pearson correlation $r = -0.96$ for males; $r = -0.97$ for females).

Figure 1b and d presents the equivalent trends for males and females, respectively, in persons aged 5 yearsor older. This shows what the trends are when child mortality is ignored. Again, mean ages of death



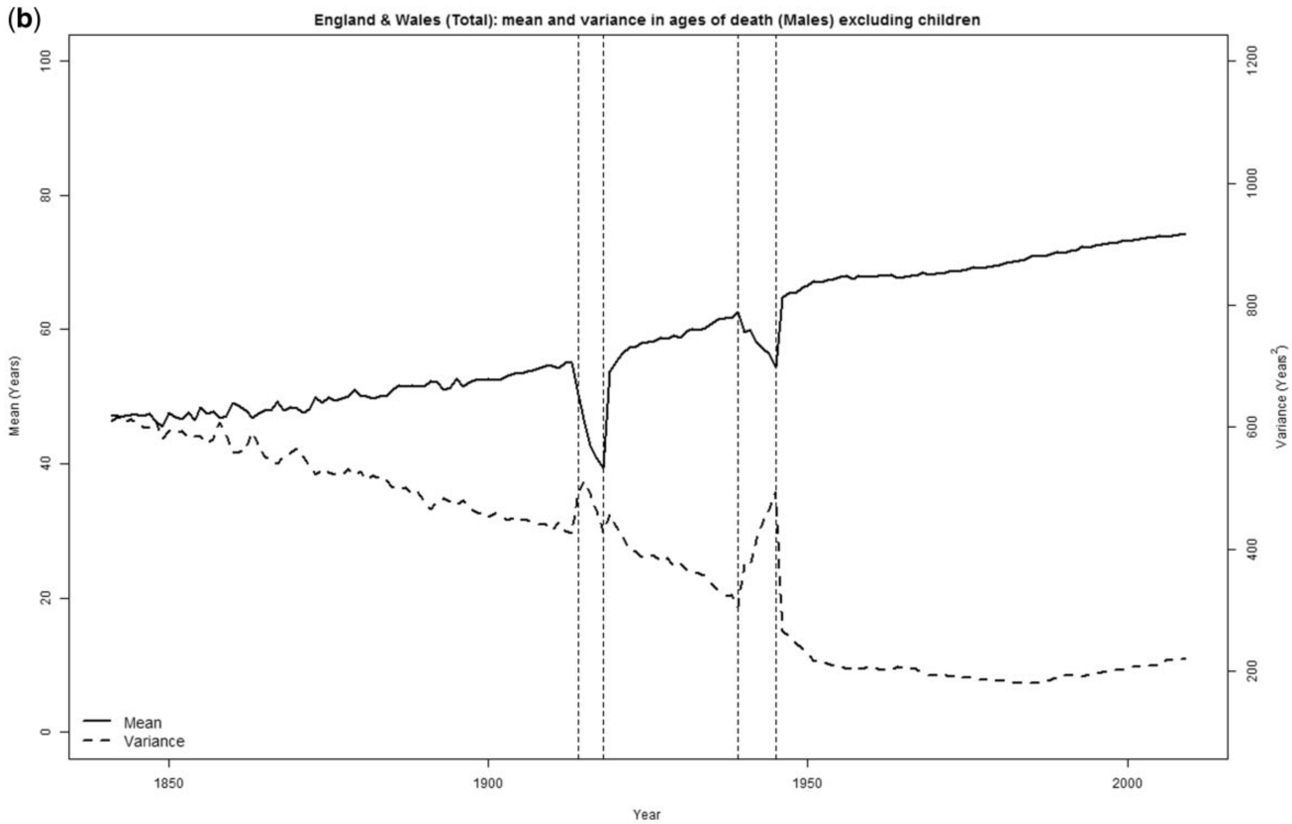
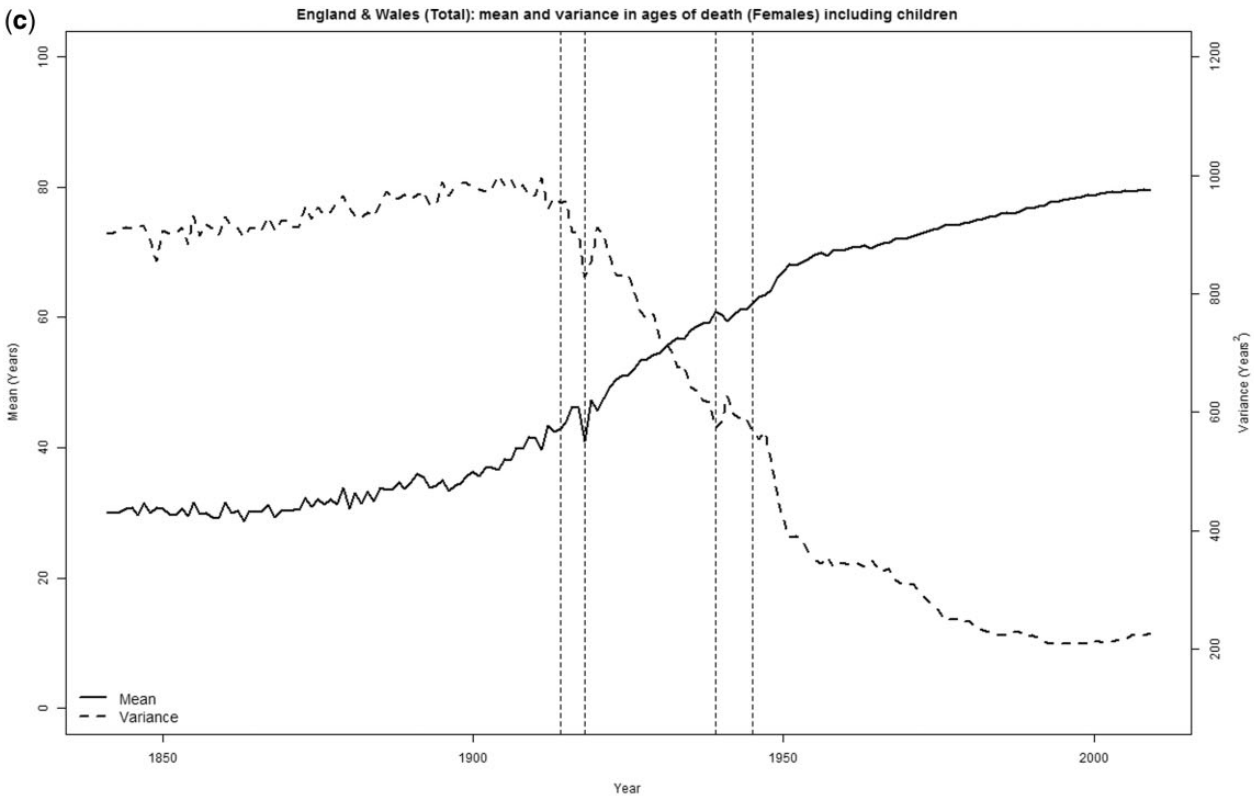


Figure 1 Mean age of death and variance around mean age of death in England & Wales from 1841 to 2005. Vertical lines indicate the years 1914, 1918, 1939 and 1945. a) Males, all ages. b) Males, excluding under fives. c) Females, all ages d) Females, excluding under fives

(continued)

(c)



(d)

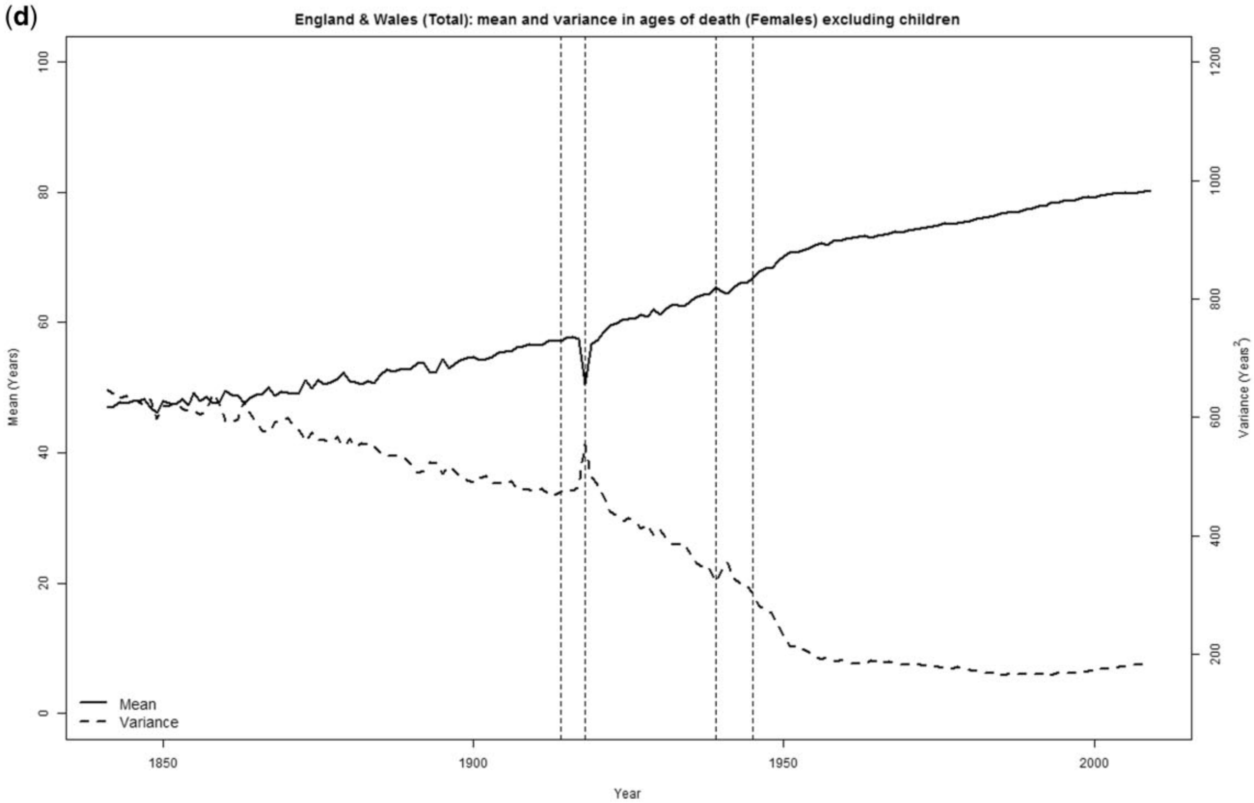


Figure 1 Continued

have increased over this time period, but were more gradual, continuing throughout the observed period, rather than mainly occurring during the first half of the 20th century. The strong inverse correlation between the mean and variance is still present when very young deaths are excluded (Pearson correlation $r = -0.98$ for males, and $r = -0.99$ for females).

The impact of the World Wars

Around the time of the two World Wars, the mean and variances briefly cease to be inversely correlated and instead both spike downwards. This is much more strongly pronounced for males than females. This could be caused by high levels of mortality among men fighting in the wars, including dying from diseases associated with warfare and the trenches and battlefields, placing a much increased mortality risk on young adults within a relatively small age range. Data are reported separately for the civilian population only, and are presented in Figure 2. We see that the concurrent downwards spike was not present or much attenuated for civilians, and that both the male and female trends are very similar to each other, indicating strong support for this hypothesis.

Contour plots

Figure 3 shows the mortality rate contour plots of the same England and Wales datasets. A number of complex patterns are observed, some specific to either males or females, and others common to both genders. Bimodal or 'bathtub' mortality patterns can be seen in the contour plots by considering any vertical transect through any of our maps, which presents a cross-sectional snapshot of the relationship between mortality rates and human age in any given year. Comparing a cross section from around 1900 with another around 2000, it is clear the mortality distribution has changed radically as public health has improved. Child mortality rates have reduced drastically, as the thick concentration of broadly parallel lines all but disappears.

Mortality patterns at older ages

Background levels of relatively high mortality risk that used to be present during early middle age, and in peoples' 30s and 40s, have been pushed back to much older middle age and early old age: now into peoples' 50s and 60s. This is made apparent by considering the contour line marked '0.01'. If mortality rates were to have become markedly more compressed over time, then the lines at older ages would have moved closer together. Instead, they appear to be moving upwards broadly in parallel, suggesting that average ages of death can be expected to continue to increase for a little longer yet, rather than reach a hard limit of older age in the very near future.

The direct effect of the World Wars

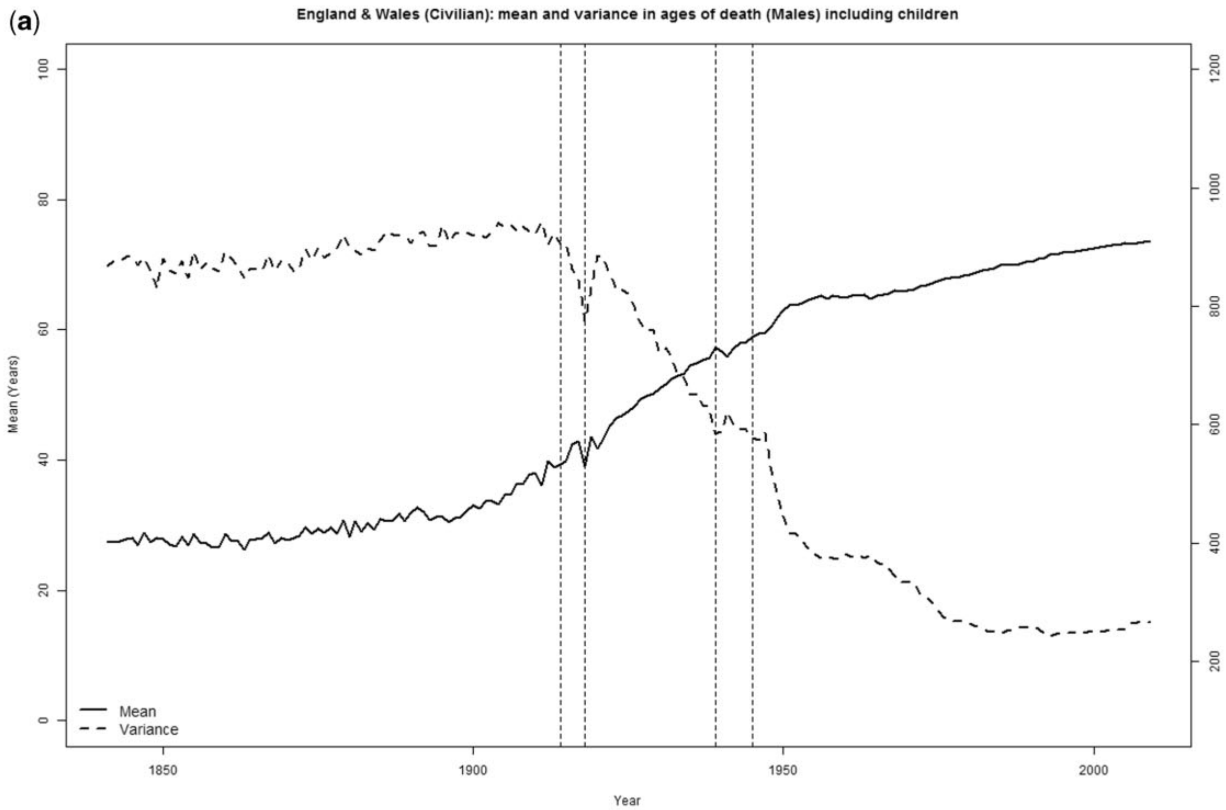
Both World Wars have a clear effect on the contour maps. A long, thin 'shard' of increased mortality is present for males coinciding with World War I, and a less pronounced shard coincides with World War II. The mortality hazard shards begin at age 18 years, the youngest age of usual recruitment, and extend to younger middle age (the oldest age of much recruitment). These tightly wound contours show how severe the effects of the WorldWar I were, as for a brief period young adult males had higher rates of mortality than much older men. Another indication of the direct effect of both World Wars is through the patterns of vertical disruption observed to the upper and lower contour lines during the years in which these events occurred. Looking at the equivalent demographic maps for the civilian population only, as shown in Figure 4, further indicates the extent to which the excess mortality risk was due to warfare. For female civilians (Figure 4b), barely any effect is noticeable whatsoever. For male civilians (Figure 4a), very little effect is apparent for World War II. For the World War I, however, a large effect is still noticeable, indicating much of the cause of the excess mortality impact may have been something separate to, but that coincided with, warfare.

Evidence of an indirect, cohort effect of World War I

A diagonal 'tear' is present in the figures as well, suggesting a cohort effect. To illustrate this, Figure 5 presents the map shown in Figure 3a annotated with a diagonal bar indicating the cohort of interest and leading to an approximate birth year. We see that this cohort is associated with a drop in the mortality rate contours in older ages compared with any cohort born just a few years previously, implying this cohort experienced greater lifetime mortality risks at all ages. The extent to which the contours drop downwards for this particular contour gives an indication of the magnitude of this effect. A crude visual estimate would suggest being born within this cohort could lead to mortality rates equivalent to those that might otherwise be expected of persons around 5 years older than themselves, in that the downwards dip across the vertical axis is around 5 years. The strong indication that this is a World War I birth cohort is that, if the diagonal line were to be traced back left and downwards, it would intersect the horizontal axis (i.e. reach age = 0) at round about the time of World War I wars, and especially that war may not in fact be as good for babies and other young children as was once thought.[17]

International comparison of trends

Similar patterns, including the probable 1918 cohort effect, are shown in other datasets, available in the Supplementary Appendix (available as Supplementary data at *IJE* online). For illustration, Figure 6a shows the contour map for Italy, where the tear is also apparent. Conversely, the effect is not present in Japan



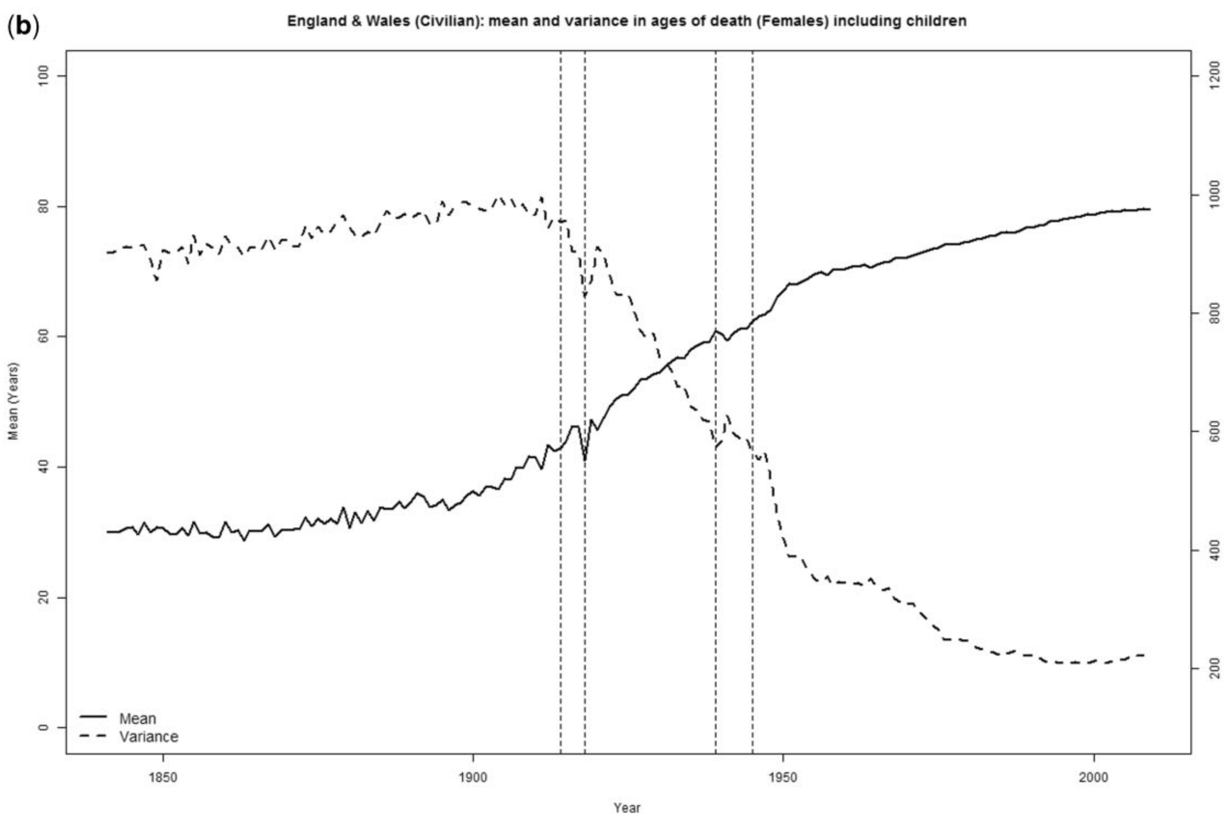


Figure 2 Mean ages of death and variance around mean age of death, England & Wales, 1841 to 2005, Civilian population only a) Males, all ages, civilian population only. b) Females, all ages, civilian population only

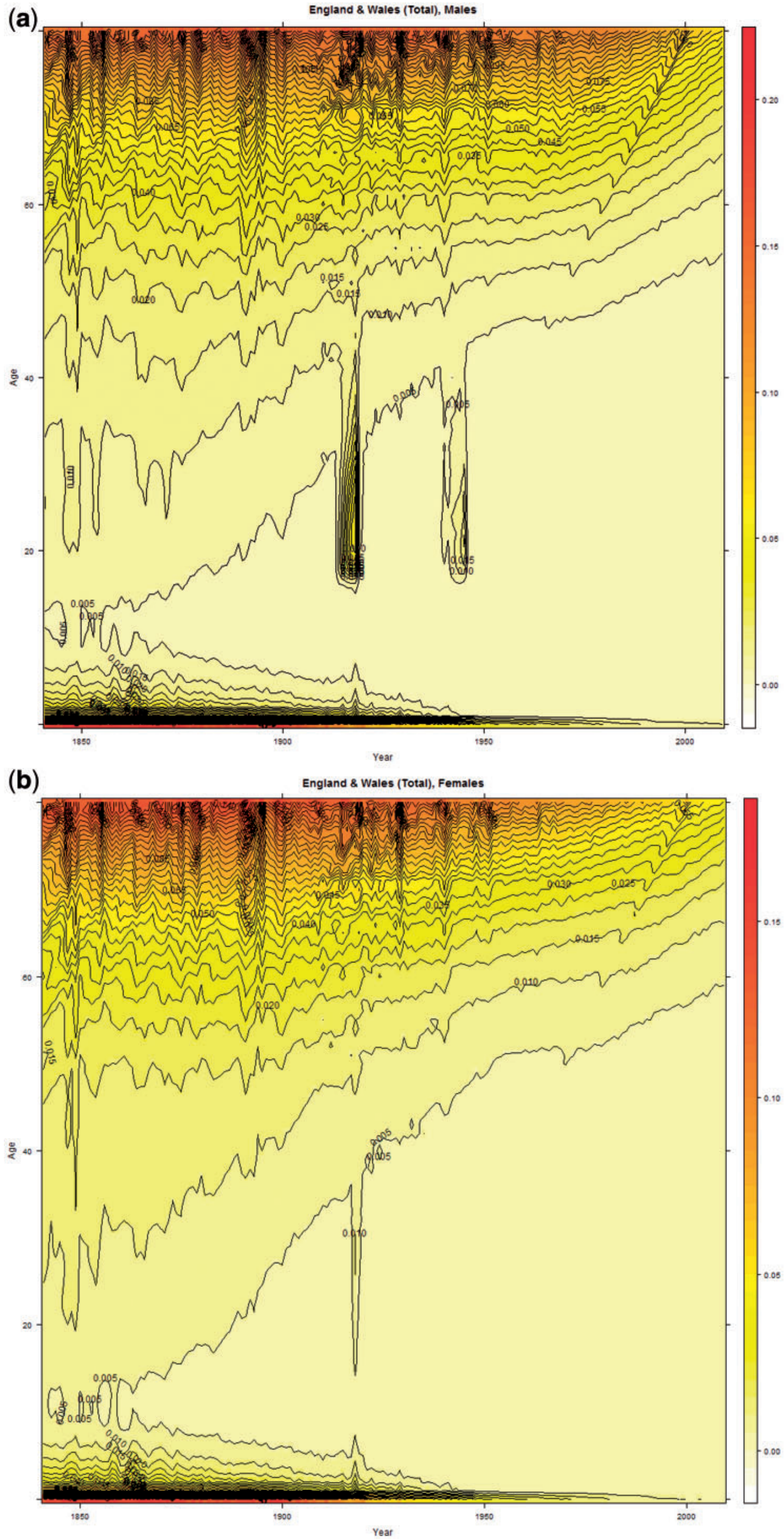


Figure 3 Contour plots of mortality rates, England & Wales, 1841 to 2005. a) Males in England & Wales, 1841 to 2005. b) Females in England & Wales, 1841 to 2005

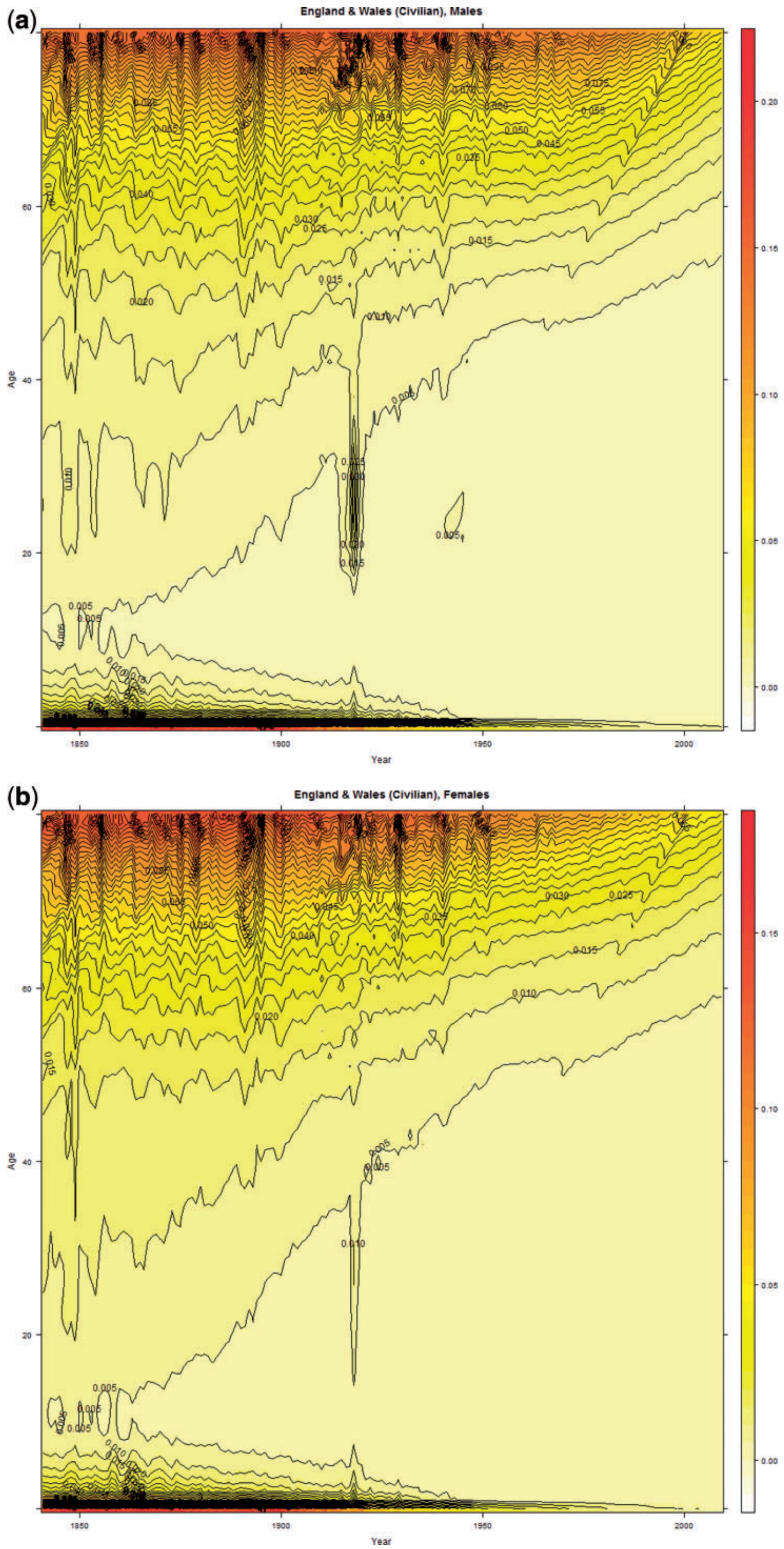


Figure 4 Contour plots of mortality rates, England & Wales, 1841 to 2005. a) Males, civilians only, England & Wales, 1841 to 2005. b) Females, civilians only, England & Wales, 1841 to 2005

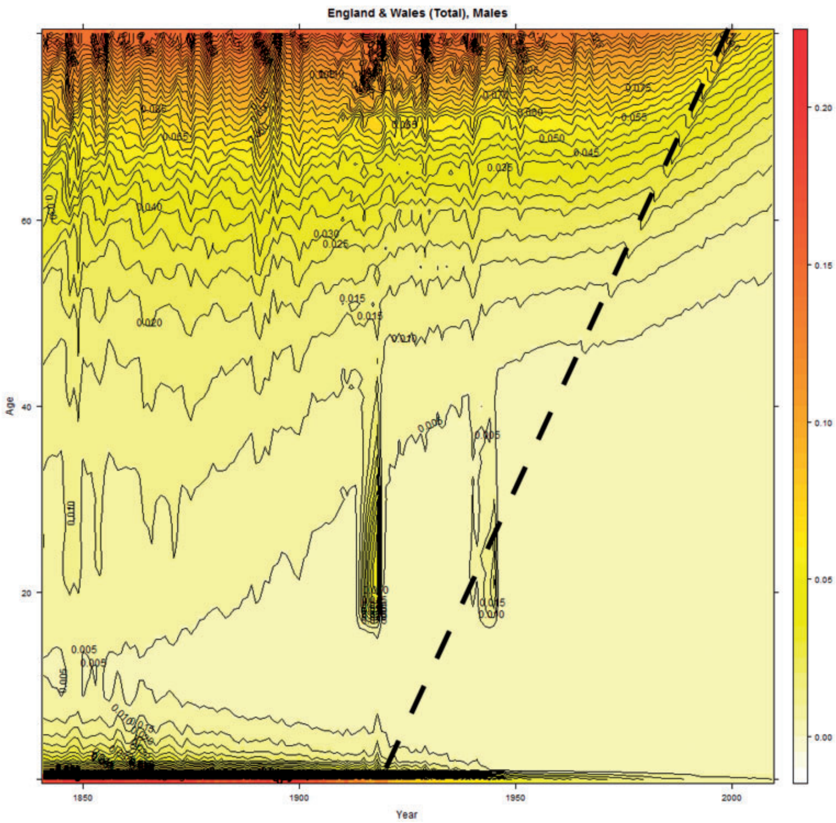


Figure 5 Contour plot of mortality rates for males in England & Wales, 1841 to 2005, with line added to indicate cohort effect

which had little or no involvement in World War I (Figure 6b). Given the effect's presence in so many datasets, it appears unlikely to be due to any form of administrative change such as a different way of registering births or deaths. A strong natural experiment in support of this position is made evident by comparing the contour maps of East Germany with West Germany, two administrative regimes inhabited by almost arbitrarily divided parts of the same 1918 population, who collected vital statistics data from the times of their formation to their reunification while not communicating a great deal with each other (and hence are unlikely to have standardized data collection methods). Figure 7 shows that despite this, the cohort effect appears almost identical in both datasets.

Discussion

Findings

This study showed how mean/variance coplots and contour plots can both be used to explore trends in vital statistics. The coplots provide a simple way of visualizing the epidemiological transition which occurred in England and Wales over the course of the 20th century, as it did in most other nations in Europe. The epidemiological transition, in which infectious disease changed from a major to a minor cause of death, is evident in the general trends indicated by our visualisations.[7] Owing to drastically reduced rates of child mortality, the 'bathtub' relationship between age and mortality has become highly asymmetrical. Both of these trends are towards longer and generally healthier lives. The 1918 cohort effect represents a temporary setback against these general trends. The fact that the variance around mean age of death, as presented previously in Figure 1 and Figure 2, appears not to have decreased since the 1950s appears to support the hypothesis that rising longevity has some life in it yet.

A possible end to the epidemiological transition?

At the very end of the study period, the variation of life expectancy stops falling and the rise in mean age appears to slow down (see Figure 1 and Figure 2). As these two are related, it may be worth pointing out the possibility that very recent years may mark the beginnings of a new period of stability similar to the period up to the year 1900 but the opposite of it. Then variance was high and mean expectancy low. From 2000 onwards the opposite might be the case. The demographic transition that has occurred may have been contained almost entirely in the

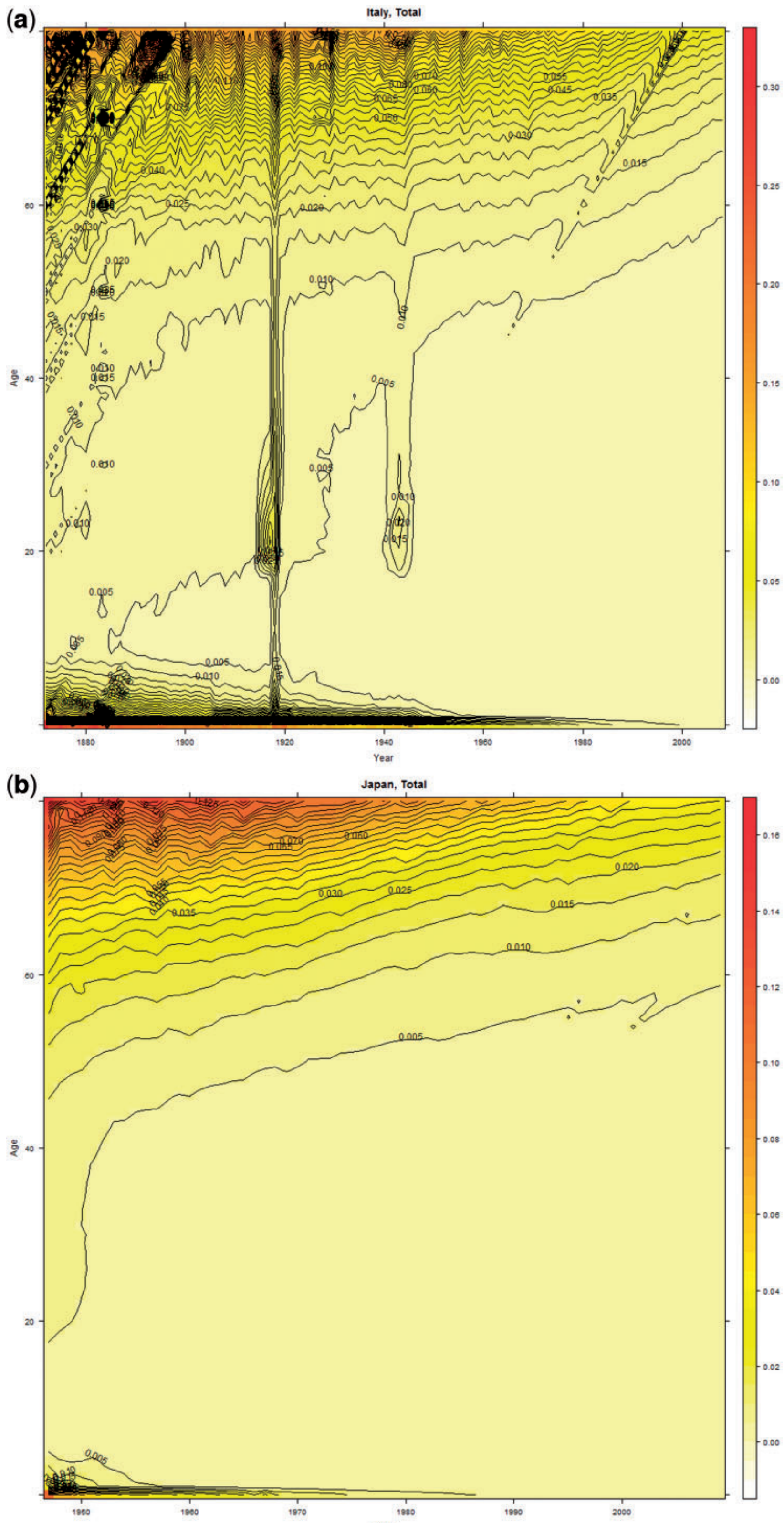


Figure 6 Italy and Japan, males and females combined. a) Italy 1872 to 2008, males and females combined. b) Japan 1947 to 2009, males and females combined

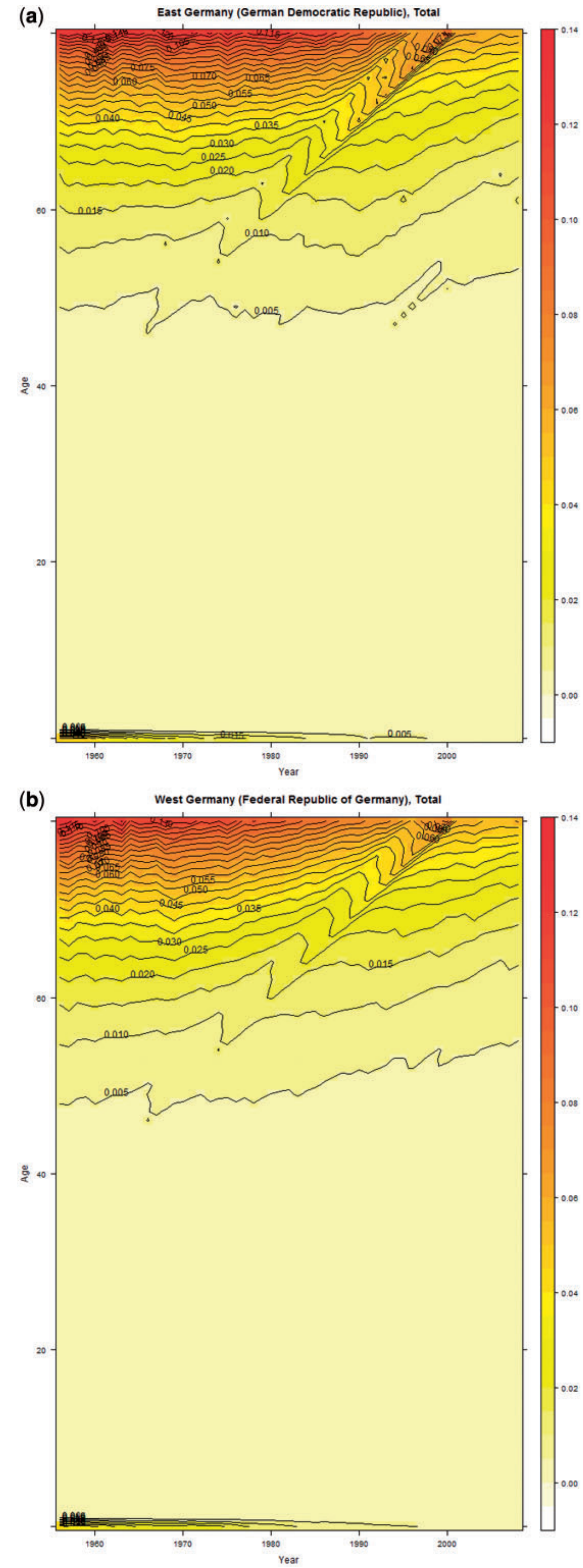


Figure 7 East and West Germany, 1956 to 2009 a) East Germany b) West Germany

period 1900–2000, and we may now be entering a new epoch, but it is too soon to say.

Shortcomings

It is not possible with the data available to disentangle the ultimate causes of the cohort effect, as both the worst infectious disease outbreak of the 20th century and an international war occurred around the same time and in the same places. All we can say is that the effect did not appear to diminish as that cohort aged. There was still an additional disadvantage associated with having been born in 1917–18 even for people reaching age 80 years. Additionally, it is not possible with only vital statistics data to explore the relationship between mortality and morbidity over time. One hypothesis we cannot test is whether higher social class families left the UK for the USA in greater than usual numbers after 1916, which may be worth considering in future work.

Relationships with previous research

In recent years there have been great advances in understanding how environmental conditions experienced in childhood or later influence health in later years.[1–3,18–23] Studies following people exposed *in utero* to the 1944 Dutch famine found excessive rates of a range of health problems, including coronary heart disease, obesity and some forms of cancer, but did not indicate increased rates of all-cause mortality.[4,18,23–29] The results presented here provide a strong indication that *in utero* exposure to events around 1918 led to reduced life expectancies in middle and older age. Recent evidence has shown that even in the USA, a country with less exposure to those factors than European nations, there exist negative effects of being part of the 1918 cohort on morbidity as well as mortality.[30] From this it should be assumed that morbidity effects exist in European and other affected nations alongside the mortality effects illustrated here.

There is already debate in the literature concerning possible ends to the demographic transition.[31,32] What this paper does is suggest that below at least age 100 there is evidence of continually falling mortality risk. Our paper includes no data for people exceeding that age.[33,34]

Implications for research

The coplots and contour plots presented in this article represent just a small sample of the hundreds of figures produced, which are available for readers in the online appendix (available as Supplementary data at *IJE* online). Coplots and contour plots have been produced for all nations where appropriate data were available from the Human Mortality Database.[12] The R code used to produce these graphs is available on request from the contact author, and we expect further exploration and analyses of the additional figures will lead to further findings and research outputs. In addition to exploring data currently available and compiled on the Human Mortality Database, the methods could also be applied to other demographic data sources, such as data generated by demographic surveillance systems of majority world populations.[35] There is also potential to use the methods to look at patterns in cause-specific mortality, or at the age and gender distribution of particular illnesses over time, such as diabetes.[36] This could help to identify, for example, which types of fatal disease were excluded as a consequence of looking at mean-variance coplots for all ages (Figure 1a and c) compared with those in persons aged 5 years or older only (Figure 1b and 1d).

Implications for practice

As Kermack and colleagues noted almost eight decades ago, the identification of cohort effects can be of practical application for the actuarial sciences, as additional information about how long people can be expected to live can help estimate pensions liabilities and set prices for annuities.[9] We are also keen to emphasize the medical implications of these findings, and others that may emerge from exploring the material presented in the online appendices (available as Supplementary data at *IJE* online). Few people from the 1918 cohort are still alive but, if conditions near the end of the World War II were similar, then a 'baby boomer' cohort effect may also be present. This would have substantial implications for healthcare planning even if the magnitude of the effect is small compared with the 1918 cohort. These 'scars' could also be compared to effects found to be associated with enhanced male mortality coincident with the onset of the early 1970s', 1980s' and 1990s' global economic recessions.[13]

Conclusion

The two methods shown here allow quick exploration of national vital statistics and comparison between nations. Mean-variance coplots allow broad epidemiological transitions to be understood and compared quickly, and contour plots allow more detailed patterns relating to age, period and cohort effects to be explored. Contour plots make it easy to identify concurrent demographic changes, including reduced child mortality and increased longevity, and make it clear when events, such as wars and pandemics, lead to disruptions in these general trends. As such, the methods allow for intuitive visual inspection of complex patterns.

Supplementary Data

Supplementary data is available at *IJE* online.

Acknowledgements

We would like to thank Tom Adams, John Brazier, Tony Danso-Appiah, John Komlos, Ravi Maheswaran, Kate Pickett, Matt Stevenson and Mark Strong for helpful advice at various points. We would also like to thank the anonymous referees who reviewed this paper for their comments, queries and suggestions.

Conflict of interest: None declared.

KEY MESSAGES

- New, high resolution ways of visualizing mortality by gender, age and time can reveal new patterns in old data. We present two ways of visualizing such data: mean-variance coplots and high density contour plots.
- The coplot suggests an end to the epidemiological transition in England and Wales.
- The contour plot shows a possible cohort effect associated with the 1918 influenza pandemic.
- Both of these hypotheses would have been very hard to generate without first seeing these new visualizations.
- Both hypotheses prompt the need for further detailed investigation. The visualizations have been generated for a large number of national datasets, and so could lead to further patterns being identified and hypotheses generated.

References

1 Davey Smith G, Marmot MG. Trends in mortality in Britain: 1920–1986. *Ann Nutr Metab* 1991;**35:**53–63.

2 Harris B. Commentary: 'The child is father of the man.' The relationship between child health and adult mortality in the 19th and 20th centuries. *Int J Epidemiol* 2001;**30:**688–96.

3 Szeter S, Mooney G. Urbanisation, mortality and the standard of living debate: new estimates of the expection of life at birth in nineteenth-century British cities. *Economic History Review* 1998;**51:**84–112.

4 Davey Smith G. Life-course approaches to inequalities in adult chronic disease risk. *Proc Nutr Soc* 2007;**66:**216–36.

[5] Leon DA. Trends in European life expectancy: a salutary view. *Int J Epidemiol* 2011;**40:**271–77.

[6] Alen Sula C. Philosophy through the macroscope: technologies, representations, and the history of the profession. *J Interact Technol Pedagogy* 2012; available at http://jitp.commons.gc.cuny.edu/philosophy-through-the-macroscope-technologies-representations-and-the-history-of-the-profession/ (27 June 2013, date last accessed).

[7] Wilkinson RG. The epidemiological transition: from material scarcity to social disadvantage? *Daedalus* 1994; **123:**61–77.

[8] Gompertz B. On the Nature of the Function Expressive of the Law of Human Mortality, and on a New Mode of Determining the Value of Life Contingencies. *Phil Trans R Soc Lond* 1825;**115:**513–83.

[9] Kermack W. Death-rates in Great Britain and Sweden. Some general regularities and their significance. *Int J Epidemiol* 2001;**30:**678–83.

[10] Barker DJP. The Developmental Origins of Adult Disease. *J Am Coll Nutr* 2004;**23(Suppl 6):**S588–95.

[11] Davey Smith G. Commentary: William Ogilvy Kermack and the childhood origins of adult health and disease. *Int J Epidemiol* 2001;**30:**696–703.

[12] Human Mortality Database; University of California, Berkeley (USA), and Max Plank Institute for Demographic Research (Germany). 2011. Available at www.mortality.org (11 June 2011, date last accessed).

[13] Rigby JE, Dorling D. Mortality in relation to sex in the affluent world. *J Epidemiol Commun Health* 2007;**61:** 159–64.

[14] Lexis W. *Einleitung in die Theorie der Bevölkerungsstatistik* [Introduction to the theory of population statistics], 1875; available at http://www.worldcat.org/title/einleitung-in-die-theorie-der-bevolkerungsstatistik/oclc/27127671 (27 June 2013, date last accessed).

[15] Sarkar D. *Lattice: Multivariate Data Visualization with R*. New York: Springer, 2008.

[16] R Development Core Team. *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing, 2011; http://www.r-project.org/ (27 June 2013, date last accessed).

[17] Dwork D. War is Good for Babies and Other Young Children: A History of the Infant and Child Welfare Movement in England 1898–1918. London: Tavistock, 1987.

[18] Davey Smith G. Epidemiology, epigenetics and the 'Gloomy Prospect': embracing randomness in population health research and practice. *Int J Epidemiol* 2011;**40:** 537–62.

[19] Ben-Shlomo Y, Davey Smith G. Deprivation in infancy or in adult life: which is more important for mortality risk? *Lancet* 1991;**337:**530–34.

[20] Borghol N, Suderman M, McArdle W *et al*. Associations with early-life socio-economic position in adult DNA methylation. *Int J Epidemiol* 2012;**41:**62–74.

[21] Hyman SE. How adversity gets under the skin. *Nat Neurosci* 2009;**12:**241–43.

[22] Ma YT, Collins SI, Young LS, Murray PG, Woodman CBJ. Smoking initiation is followed by the early acquisition of epigenetic change in cervical epithelium: a longitudinal study. *Br J Cancer* 2011;**104:**1500–04.

[23] Tang LP, Macleod JA, Hobbs FDR, Wharton BA, Davey Smith G, Stewart PM. Fetal origins of adult disease: tracing and recruitment of offspring whose mothers participated in a trial of nutritional supplementation during pregnancy – the Sorrento experience. *Nutr Bull* 2004;**4:** 310–16.

[24] Horrell S, Humphries J, Voth HJ. Destined for deprivation: Human capital formation and intergenerational poverty in nineteenth-century England. *Explorations in Economic History* 2001;**38:**339–65.

[25] Thayer ZM, Kuzawa CW. Biological memories of past environments: epigenetic pathways to health disparities. *Epigenetics* 2011;**6:**798–803.

[26] Roseboom TJ. Coronary heart disease after prenatal exposure to the Dutch famine, 1944-45. *Heart* 2000;**84:** 595–98.

[27] Painter RC, Roseboom TJ, Bleker OP. Prenatal exposure to the Dutch famine and disease in later life: an overview. *Reprod Toxicol* 2012;**20:**345–52.

[28] Elias SG, Peeters PHM, Grobbee DE, van Noord PAH. Breast Cancer Risk After Caloric Restriction During the 1944-1945 Dutch Famine. *J Natl Cancer Inst* 2004;**96:** 539–46.

[29] Roseboom TJ, van der Meulen JHP, Osmond C, Barker DJP, Ravelli ACJ, Bleker OP. Adult survival after prenatal exposure to the Dutch famine 1944-45. *Paediatr Perinat Epidemiol* 2001;**15:**220–25.

[30] Almond D. Is the 1918 Influenza Pandemic Over? Long-Term Effects of In Utero Influenza Exposure in the Post-1940 U.S. Population. *J Polit Econ* 2006;**114:**672–712.

[31] Omran AR. The Epidemiologic Transition: A Theory of the Epidemiology of Population Change. *Milbank Q* 2005;**83:** 731–57.

[32] Dorling D. *Population 10 Billion: The Coming Demographic Crisis and How to Survive It*. London: Constable, 2013.

[33] Olshansky SJ, Carnes BA, Désesguelles A. Prospects for longevity. *Science* 2001;**291:**1491–92.

[34] Oeppen J, Vaupel JW. Broken limits to life expectancy. *Science* 2002;**296:**1029–31.

[35] Sankoh O, Byass P. The INDEPTH Network: filling vital gaps in global epidemiology. *Int J Epidemiol* 2012;**41:**579–88.

[36] Cardwell CR, Stene LC, Joner G *et al*. Birth order and childhood type 1 diabetes risk: a pooled analysis of 31 observational studies. *Int J Epidemiol* 2011;**40:**363–74.