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Visualizing Age-Period-Cohort Trend Surfaces: A Synoptic Approach

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Jolley D (Cancer Epidemiology Centre, 1 Rathdowne Street, Carlton South, Australia 3053) and Giles GG. Visualizing age-period-cohort trend surfaces: a synoptic approach. *International Journal of Epidemiology* 1992; **21**: 178–182. Mortality data from 1950 to 1986 in Australia have been used to exemplify a method of displaying trends by age and cohort in populations over time. The visual summary or synoptic method illustrated here is similar to a topographic map with age and calendar time as its ordinates. This method is complementary to conventional analyses of age-period-cohort data which lack a summary graphic view other than that provided by the trend in age-standardized rates or a three dimensional perspective plot. Mortality from ischaemic heart disease (IHD), lung cancer and motor vehicle accidents are used as examples of the method and illustrate its utility when dealing with different forms of mortality trend e.g. cross-sectional cohort, and mixed trends.

INTRODUCTION

The study of populations across time is fundamental to the science of epidemiology. The examination of time trends in mortality has been used for many descriptive purposes. Such trend data have been important indicators of the impact of disease on communities and have been useful in making future predictions.[1–3] They have also been used to assess the effects of interventions and treatments and to formulate hypotheses for aetiological research. For example, recent rises in mortality from cervical cancer in young women have led to much discussion and research, to theories of a new disease and to the implication of human papilloma virus in its carcinogenesis.[4]

The advent of modern computers has encouraged the development of age-period-cohort (APC) modelling in an attempt to separate these three parameters by statistical means. There remains an identifiability problem (in that given any two of the parameters, the third can be derived).[5] Various ways have been suggested to overcome this problem; none have met with widespread acceptance and APC modelling remains controversial.[5–14] Kupper advises that 'Whatever statistical modelling approach is used to analyse APC data, it should be carried out in conjunction with detailed graphical analyses'.[15] Unfortunately, there are also problems to overcome when examining and illustrating APC trends graphically. Conventional analyses of long-term mortality data yield age- and sex-specific rate estimates over time. These are usually displayed as either age-sex specific trends by year of death or for separate cohorts based on year of birth. In this way detailed information is made available to assess trends in the several discrete age, period and cohort strata. In certain situations this method works very well e.g. Dorn and Cutler's analysis of lung cancer mortality in US males.[16] The detail, however, can at times be visually excessive and difficult to comprehend. Also, the small number of events that is often obtained in certain age and calendar time cells lead to highly variable rate estimates which produce graphically eccentric trends and further increase the difficulty of interpretation.

Additionally, in conventional analyses no summary impression of the overall population mortality experience is usually given other than the trend in the age standardized rate. This rate, unfortunately, conceals any heterogeneity of trend by age or cohort. With the development of computer graphics in recent years some attempts have been made to provide graphical solutions to this problem. One example is the National Cancer Institute's three dimensional perspective plots of age-specific rates by calendar year.[17] These use 'hidden line elimination' techniques to illustrate a three dimensional surface. They are attractive to look at and give a general impression of the gross trends but have two difficulties. First it is difficult to locate point values on the surface and second, complex surfaces hide useful information about any underlying trends.

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In an attempt to compensate for this, two views are given of each mortality surface. It is not easy in such situations to comprehend the total mortality experience of the population. The pictures are either too simple or too complex. In this communication a simple method of portraying mortality data is demonstrated that provides a useful visual summary or synopsis of the pattern of trends by age, period and cohort. Although suggested more than 20 years ago,[18] this method has required advances in computer graphics technology to demonstrate its utility.

METHODS

The proposed method to produce a comprehensible overview or 'synopsis' of trends in mortality by age and calendar year is borrowed from the earth sciences. In the examples given below a matrix of mortality rates, by age and by year of death, was input to numerical algorithms which produced lines connecting points of approximately equal interpolated values. These isopleths of mortality rates, or 'isothanats' (Gr. iso-equal, thanatos-death) resemble the isobars used in conventional meterological synoptic charts and the contour lines on topographic maps. The mortality process can thus be viewed as topographic surface of high and low points, of hills and valleys, saddles and troughs where the co-ordinates of latitude and longitude are substituted by age and calendar year respectively. Trends across calendar time are perceived as isothanat deviations from straight lines drawn parallel to the time (vertical) ordinate. Isothanat deviations toward decreasing age are interpreted as increasing mortality. Deviations toward increasing age indicate decreasing mortality; and the compression of deaths into older age groups. As in conventional topographical maps with equal contour intervals, the closer the isolines the steeper the slope. Individual cohorts can be indicated on the synoptic chart by diagonal lines drawn to connect the appropriate calendar year and age coordinates (the 1900 cohort will be aged 30 in 1930, 40 in 1940 etc). Each cohort moves over the mortality surface as it marches diagonally across the chart. The mortality experience of each cohort can be immediately obtained from the values and intervals of the isothanats that it crosses.

Annual mortality data for ischaemic heart disease (IHD), lung cancer, and motor vehicle accidents were obtained by sex and 5-year age group to 85+ for the years 1950 to 1986 from Australian Bureau of Statistics publications.[19,20] Data processing and display were accomplished on a Sun III workstation using the 'S' statistical package.[21] The data were manipulated into an array of age-specific rates by calendar year from 1950 to 1985. Using a contouring algorithm in 'S', isothanats were plotted with age as the horizontal axis and year of death as the vertical axis. Using 'S', the contour intervals were able to be modified, selectively printed, or highlighted. Selected cohort lines were added as diagonals connecting appropriate year and age coordinates.

It is not the intention of this communication to discuss technical details of the contouring algorithm, or the precision and optimal discreteness of the contours. To a large degree these will depend on the software and data that are available. The algorithm used in the 'S' software is based on bivariate interpolation.[22,23] The precision of the contours can be evaluated by using bootstrapping methods[24] or similar procedures such as plotting the outcomes from several simulations using the observed rates as Poisson means. These methods yield a confidence envelope within which the contour line probably lies. The data used in these analyses were available in 5-year age groups. The input of annual data would obviously have included more random noise, on the other hand, aggregating the data into decades might have reduced interesting detail. In further analyses, the optimal choice will be obtained by trial and error; the use of 5-year age groups probably remaining the default.

To illustrate the utility of the proposed synoptic method, graphical analysis was limited to male mortality for three different causes of death. For each cause of death the same data were illustrated using a conventional cohort plot, a three dimensional perspective plot and a synoptic plot.

RESULTS AND DISCUSSION

Figure 1 contains three graphs which each illustrate trends in mortality from IHD in male Australians between 1950 and 1985. The conventional cohort analysis (Figure 1a) is difficult to interpret because of the lack of cohort effect and the close overlapping of individual cohorts' curves. It can be seen that each of these has a flexion downwards indicating the presence of a modest cross-sectional decline in rates. The perspective plot (Figure 1b) does not yield much more information. An examination of the top edge of the plot reveals a small maximum about half way which then declines as it proceeds toward recent time. The synoptic chart (Figure 1c) is in fact a vertical view of (Figure 1b). The information displayed in the synopsis has been selected, reduced and smoothed. The information is much easier to assimilate. Reading from the bottom to the top the isothanats are initially virtually parallel to the time ordinate indicating absence of secular trend. After about 1965 the isothanats all diverge toward

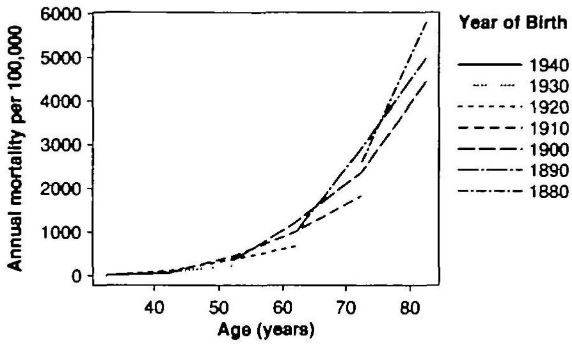

FIGURE 1a *A conventional cohort display of mortality from ischaemic heart disease (IHD) in Australian males, 1950–1985. Age-specific mortality rates per 100000 males per year are plotted separately for each birth cohort.*

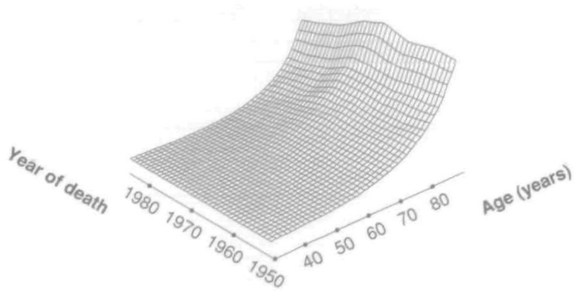

FIGURE 1b *A perspective plot showing IHD mortality in Australian males, 1950–1985, by age at death and year of death. The vertical axis represents IHD mortality per 100000 males per year at each age and year of death combination.*

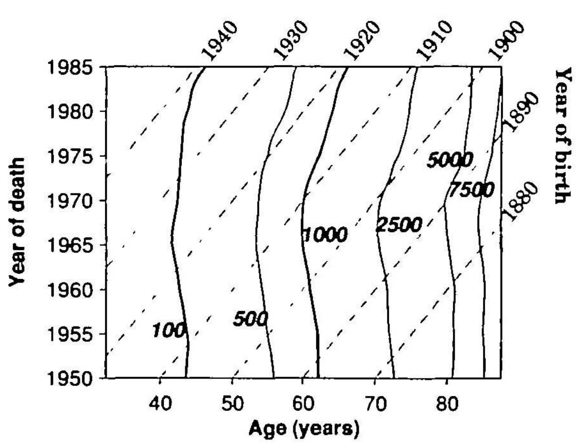

FIGURE 1c *A synoptic chart of IHD mortality in Australian males, 1950–1985, by age at death and year of death. Solid lines connect points with equal mortality rate (per 100000 males per year). Birth cohorts are indicated by broken lines.*

increasing age. This is interpreted as a cross-sectional compression of mortality toward older ages and a net mortality benefit. Since the middle 1960s Australian men have been living longer before dying of IHD. This trend is not unique to Australia; similar declines have been observed in other Western countries.[25] The cross-sectional effect at all ages points to a ubiquitous environmental effect; a general population lifestyle change rather than high-risk group intervention strategies with surgery and drugs.

The lung cancer experience is very different (Figure 2). The cohort graphs (Figure 2a) indicate some cohort effects particularly with respect to declining rates with old age. The perspective plot (Figure 2b) has much more relief than that for IHD. The epidemic of lung cancer in male Australians has built a veritable mountain of deaths. In its upper extreme the surface appears to have peaked. It is only when the synoptic chart (Figure 2c) is viewed, however, that the mortality peak is identified. A discrete focus of rates of at least 500 per 100000 per annum represents the epidemic peak which was reached in men aged about 80 years in the late 1970s and early 1980s. These men were born around the turn of the century. Their rates are now decreasing. The synoptic chart suggests that the epidemic has peaked and that reducing rates with age are to be expected from now on as is evidenced by the isothanats diverging toward increasing age since the late 1970s. For example, the 1910 cohort will not obtain as high rates as their brothers a decade earlier and although their rates are presently peaking and flattening, they have not turned down. If the mortality trend surface is symmetric in time, it should take 25–30 years to return to the 1950s level of mortality, which was when the dangers of tobacco smoking were first beginning to be realized. The declining epidemic of lung cancer is fully consistent with the declining smoking rates in male Australians in recent decades. This pattern is not seen for female smoking rates or lung cancer mortality.[26]

The third figure illustrates mortality trends in Australian males from motor vehicle accidents (MVA). This set of graphs is the most complex of the three examples. In this instance the cohort graphs (Figure 3a) show a consistent peak mortality in young males and some variability with increasing age. The perspective plot works quite well in this example (Figure 3b) giving an immediate impression of a large ridge of mortality in early adulthood followed by a trough in middle age to increase again in the elderly. The perspective plot indicates a 'peak' in elderly males about half way along the time axis. This then declines abruptly as the axis proceeds towards the present. This

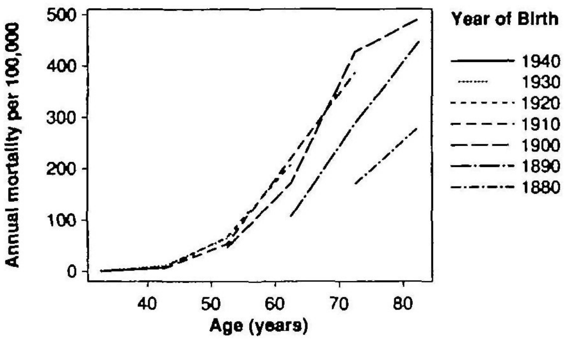

FIGURE 2a *A conventional cohort display of mortality from lung cancer in Australian males, 1950–1985. Age-specific mortality rates per 100 000 males per year are plotted separately for each birth cohort.*

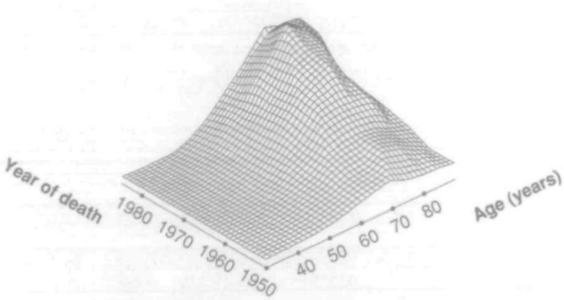

FIGURE 2b *A perspective plot showing lung cancer mortality in Australian males, 1950–1985, by age at death and year of death. The vertical axis represents lung cancer mortality per 100 000 males per year at each age and year of death combination.*

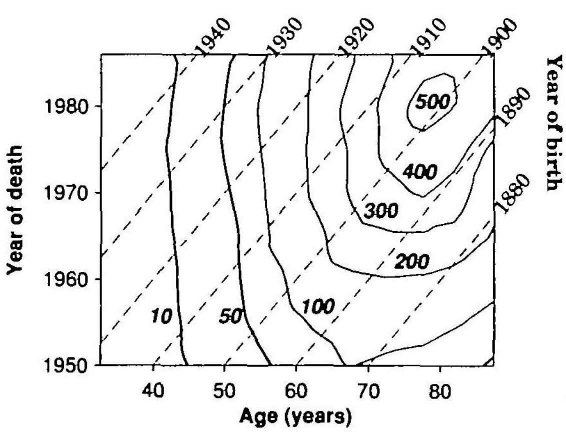

FIGURE 2c *A synoptic chart of lung cancer mortality in Australian males, 1950–1985, by age at death and year of death. Solid lines connect points with equal mortality rate (per 100 000 males per year). Birth cohorts are indicated by broken lines.*

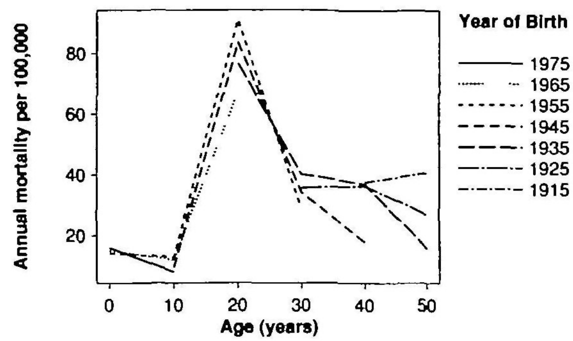

FIGURE 3a *A conventional cohort display of mortality from motor vehicle accidents (MVA) in Australian males, 1950–1985. Age-specific mortality rates per 100 000 males per year are plotted separately for each birth cohort.*

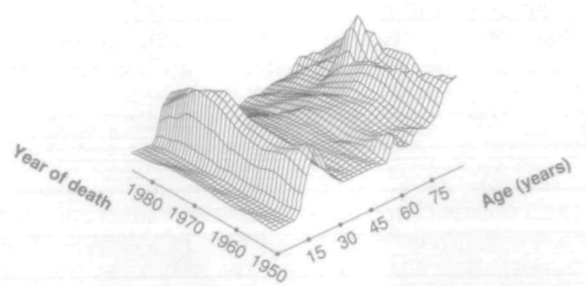

FIGURE 3b *A perspective plot showing MVA mortality in Australian males, 1950–1985, by age at death and year of death. The vertical axis represents motor vehicle accidents mortality per 100 000 males per year at each age and year of death combination.*

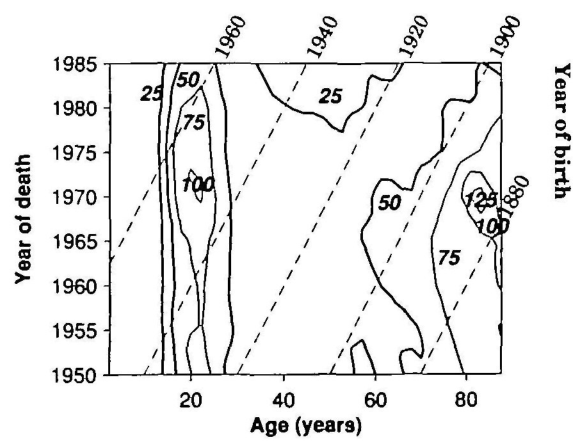

FIGURE 3c *A synoptic chart of MVA mortality in Australian males, 1950–1985, by age at death and year of death. Solid lines connect points with equal mortality rate (per 100 000 males per year). Birth cohorts are indicated by broken lines.*

peak is also seen in the ridge of high mortality in younger males although it is not as accentuated as in the elderly. The surface is complex and comprehension is improved by examining the synoptic plot. There is a strong age effect at all calendar years. There are also strong cohort effects apparent.

The peak mortality experienced by elderly males was achieved around 1970 by the 1890 birth cohort. Succeeding, younger cohorts have much reduced mortality. Their isothanats slope sharply toward increasing age. Death by MVA in the over 70s in 1985 was a rare occurrence. The peak mortality in younger men also occurred around 1970 centred on the 1950 birth cohort, but this has also declined subsequently. If the synoptic process is extended by extrapolating the isothanats one can envisage the mortality surface becoming increasingly flat. This possibility is presaged by the meandering nature of the 25 per 100000 person years isothanat in middle age describing a low, flat mortality surface. The occurrence of the peaks and subsequent decline in the mortality from MVA in Australian males around 1970 has some significance for public health. Legislation was introduced in Victoria in 1970 to make the wearing of seatbelts compulsor for all motor vehicle passengers. By January 1972 this applied throughout Australia.[27] This population intervention has obviously been successful. An interpretation of the synoptic chart is that the success was most immediately felt in the older age groups whose mortality from MVA has reduced enormously. The epidemic of MVA deaths in young men peaked and continues to decline. It is unlikely, however, that the mandatory wearing of seatbelts will ever entirely diminish MVA deaths in this high risk taking age group.

The synoptic chart method has been shown to augment the conventional approaches to the graphical analysis of age, cohort and period trends in mortality. This approach has other obvious applications to morbidity and service delivery data. We hope that it will be used.

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