Modeling age-related changes from late middle age in men and women

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Abstract
We present a new approach to modeling health transitions in mean and women from late middle age (55+). This approach is based on a parametric representation of health transitions using a modified Poisson distribution for the probabilities of health changes. In the Canadian National Population Health Survey (n=4330, 2548 women, at baseline in 1994), health status was defined by a deficit count, using 33 health-related variables. Changes in deficit count were followed up over 4 consecutive 2-year intervals to 2002. The model stratified by sex predicts health changes (improvement or worsening at any degree, and death) with an exceptionally high accuracy (R^2 ~0.90). The model employs only four sex-specific parameters: two represent health transition of survivors, and two represent the probability of death. The parameters reflect the men/women difference in transitions: despite women show higher level of deficit accumulation, they show lower mortality than men at any deficit level.

Background:
As people get older, they are more likely to experience ill health. This is reflected in a lower average active life expectancy, and in higher levels of functional impairment and frailty. Even so, many people do improve their health, by making changes in their lifestyles, and through the effects of health care. Comparatively few epidemiological studies have investigated how such changes occur over time and how they are related to adverse outcomes (e.g., mortality). Here we report a stochastic model of health transitions during aging and illustrate its performance in a large Canadian population cohort analyzed separately in men and women.

Methods:
Population
The data came from the National Population Health Survey (NPHS) a longitudinal survey on the health of Canadians conducted in 1994, 1996, 1998, 2000 and 2002. We studied 4330 people (2548 women) aged 55+ assessed in 1994 using the health related questionnaires with the follow up of those who survived at the next four waves. Thirty three health related dichotomized variables (deficits) were used to calculate the deficit accumulation count in each individual. The empirical transition probabilities between the different states of health (defined as a number of deficits count) were calculated from the survey data.

The model
The transitions between the states were modeled using a modified Poisson distribution [Mitnitski et al., 2006; Mitnitski et al., 2007]:

$$P_{nk} = \frac{\bar{k}_n^{\,k}}{k!}\exp(-\bar{k}_n)\cdot(1-P_{nd}), \qquad (1)$$

where $\bar{k}_n$ is a positive parameter (the mean number of deficits after transition from the state with n deficits) that linearly increases with n:

$$\bar{k}_n = \bar{k}_0 + \beta_1 n \tag{2}$$

and the probability of death exponentially increases with n:

$$P_{nd} = P_{0d}\exp(\beta_2 n) \tag{3}$$

($P_{nd} \leq 1$). Four parameters, the background parameters: $\bar{k}_0$, P_{0d}, and the increments: β_1, β_2 were estimated from observational data. Nonlinear fitting was used to estimate the parameters of the model. Goodness of fit of the model was evaluated using R^2. All analyses were conducted using Matlab 7.4

Results and discussion:
Of the total 33 deficits nobody has more than 22 deficits. This limit is age invariant. The modified Poisson model with four parameters fitted observational data with a very high accuracy (Table 1), R^2>0.85. The example of how model fits observational data is shown in Figure 1 for women for the 2-year transitions, the probabilities of transitions are shown for first 12 states: the lines (model) and the circles (observational data) virtually coincide; only fewer than 5% of people show 12 or more deficits. In Table 1, the parameters are presented separately in men and women for 4 time intervals from two to eight years.

The parameters clearly monotonically change over time (Figure 2) but only the increment β_1 and the background parameter $\ln P_{od}$ are significantly different between men and women (Figure 2, Panel B,D).

The probability of death is shown in Figure 3. There is a substantial difference in the risks of death between men and women. This difference increases exponentially with the number of deficits at baseline. These data support the previous finding that women with the same number of deficits have better survival than men do. The relative risks of death within two years for men comparing to women with zero deficit is 1.8 but it decreases with the number of deficits to 2.0 for the people with 5 deficits at baseline and is about 2.2 for the people with 10 deficits. Thus, men have about twice as much risks of dying than women. For men, the four-year probability of dying is about the same as for 8-year probability of dying for women.

Our model is simple, shows a high level of fit and is robust (Mitnitski et al., 2006; 2007a,b). It requires no special instrumentation and derivable from existing health surveys. How this model can be accounted for the other factors (specific illnesses, or health styles) is the question motivating additional inquiries of our group.

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Table 1. The parameter estimates of the model (1)-(3) for the men and women of for two, four, six and eight year follow-up.

	Follow up	2 years	4 years	6 years	8 years
	Parameter estimates	Combined data*	Combined data**	Combined data***	
Men (n=1,782)	$\bar{k}_0$	0.80 (0.73, 0.87)	099 (0.90, 1.08)	1.05 (0.78, 1.23)	1.34 (1.00, 1.69)
	β_1	0.80 (0.77, 0.82)	0.76 (0.72, 0.81)	0.72 (0.64, 0.69)	0.66 (0.53, 0.80)
	lnP_{od}	-3.21 (-3.50, -2.92)	-2.41 (-2.61, -2.22)	-1.93 (-2.10, -1.76)	-1.53 (-1.71, -1.35)
	β_2	0.17 (0.13, 0.20)	0.15 (0.13, 0.17)	0.14 (0.12, 0.16)	0.12 (0.09, 0.14)
	R^2	0.93	0.89	0.88	0.85
Women (n=2,548)	$\bar{k}_0$	0.83 (0.78, 0.89)	1.05 (0.96, 1.15)	1.19 (1.07, 1.30)	1.58 (1.33, 1.82)
	β_1	0.86 (0.84, 0.88)	0.83 (0.80, 0.87)	0.84 (0.80, 0.89)	0.81 (0.72, 0.89)
	lnP_{od}	-3.79 (-4.21, -3.37)	-2.84 (-3.09, -2.60)	-2.34 (-2.50, -2.17)	-1.91 (-2.10, -1.73)
	β_2	0.15 (0.11, 0.21)	0.14 (0.11, 0.16)	0.13 (0.11, 0.15)	0.11 (0.09, 0.13)
	R^2	0.93	0.89	0.90	0.87

*) Combined data for each 2-year cycle (1994-1996, 1996-1998, 1998-2000, and 2000-2002)
**) Combined data for each 4-year cycle (1994-1998, 1996-12000, and 1998-2002
***) Combined data for each 6-year cycle (1994-2000, and 1996-2002

Figure 1. An example of the model fit for women for 2 year follow up: The probability of transition (vertical axis) from a given deficit state *n* (shown in each subplot) to *k* deficits (horizontal axis). Circles represent observed transitions between two consecutive cycles (for convenience of portrayal, the three cycles are averaged). The lines show the model's fit according to equations (1)-(3). The data are truncated at 12 deficits for presentation; fewer than 5% of people show 12 or more deficits.

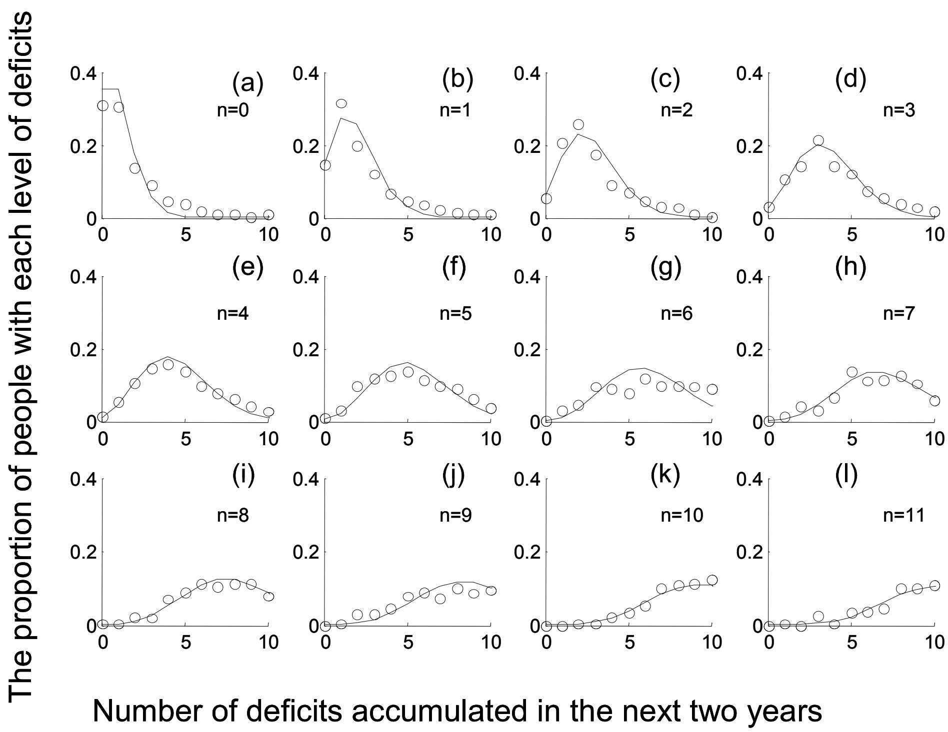

Figure 2. The parameters of the model as a function of the interval between two assessments (Table 1). In each panel, triangles indicate men and circles women. Bars represent the confidence intervals.

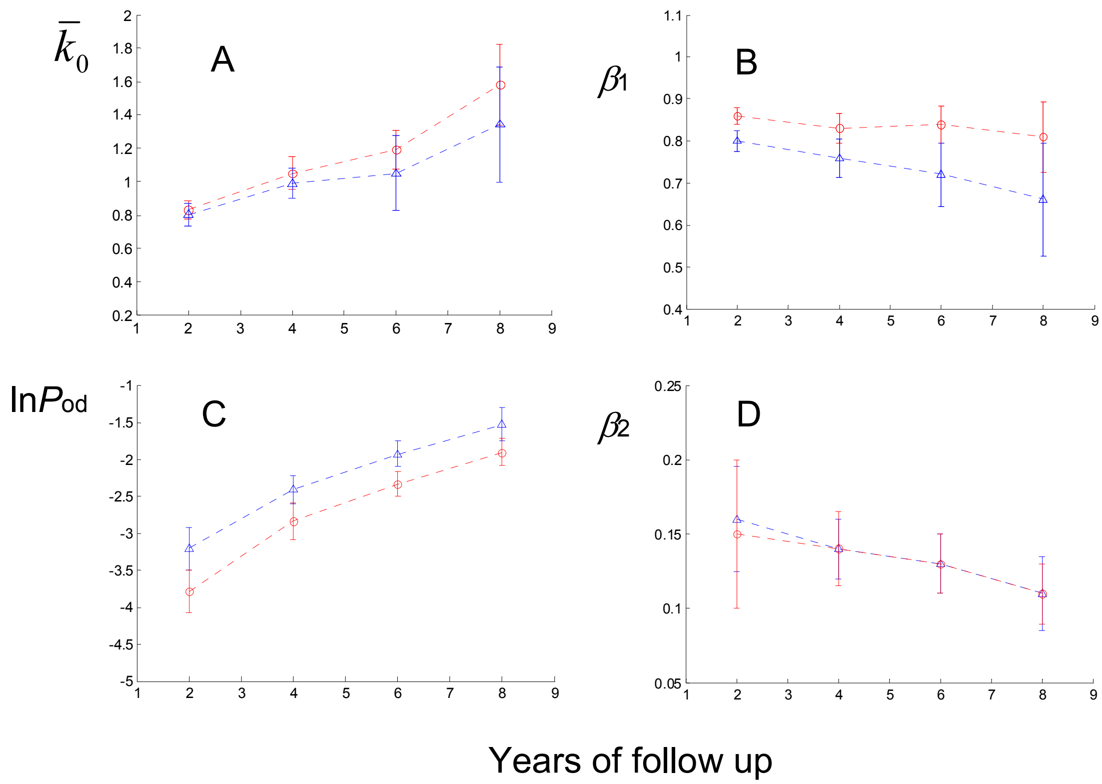

Figure 3. The probability of death as a function of the number of deficits at baseline and the interval between two assessments. Panel A: men, Panel B: women. The intercepts correspond to the values of the $exp(\ln P_{od})$ (Table 1).