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GROWTH MODELS: AN INTERESTING APPROACH TO STUDY THE EVOLUTION OF THE HEALTH STATUS OF THE ELDERLY

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ABSTRACT

Evaluating the impact of changes to services on the health status of frail elderly adults calls for longitudinal studies. Many subjects are however lost during follow-up because of the high incidence of death in this population. Traditional methods of repeated measures analysis are thus inappropriate since they ignore subjects with incomplete follow-up data. This leads to a considerable reduction in sample size and to biases. Because they are valid for all types of ignorable non-response, growth models allow, among other things, a considerable reduction in bias. The "missing at random" assumption is plausible here since death is often related to previous measures of health status. A concrete example is presented.

KEY WORDS: Growth models; Longitudinal Studies; Functional decline; Frail elderly people; Ignorable non-response.

1. INTRODUCTION

The aging of the Québec and Canadian populations requires major changes in the organization and delivery of social and health services. Longitudinal studies are needed to evaluate the impact of these changes on the health status of older adults, especially the frail ones. The high mortality rate is a distinctive feature of the aged population which makes inappropriate the use traditional methods of repeated measures analysis. Firstly, the thinning of cohorts over time decreases the power of statistical tests. But mainly, there are biases arising from the fact that subjects lost to death are certainly different from survivors being assessed on all measuring occasions.

2. GROWTH MODELS

Growth modeling is an interesting approach to study the evolution of the health status of individuals. Also called multilevel modeling for change, it addresses within-person and between-persons questions about change simultaneously with a pair of submodels. The level-1 submodel describes how each person changes over time, and the level-2 model describes how these changes differ across people (Rogosa & Willett, 1985; Bryk & Raudenbush, 1987; Singer & Willett, 2003).

2.1 Modeling linear change through time

To begin, let's postulate that change is a linear function of time. The level-1 model is then:

$$Y_{ij} = \pi_{0i} + \pi_{1i} T_{ij} + \varepsilon_{ij} \quad \text{where } \varepsilon_{ij} \sim N(0, \sigma_{\varepsilon}^{2}) \tag{1}$$

where Y_{ij}, T_{ij} and ε_{ij} are respectively the health status, the measure of time and the measurement error for subject i at measurement j.

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Equation (1) uses two subscripts, i and j, to identify individuals and occasions, respectively. Thus, i runs from 1 to n (the sample size) and j runs from 1 to t_i (the number of measurement occasions for subject i). We clearly see that the number of measurement occasions is not necessarily identical for every subject in the sample.

Two parameters, called the growth parameters, need to be estimated in equation (1): the intercept, π_{0i} and the slope, π_{1i}. The slope represents the rate at which individual i changes over time. The stochastic part of equation (1) stands for the measurement error for subject i at measurement j. The variance of ε_{ij}, σ_{ε}^{2} captures the scatter of the level-1 residuals around each person's true change trajectory.

The subscripts i for the intercept and slope parameters indicate that although the model assumes that all the individual change trajectories have a common algebraic form, it does not assume that everyone has the same exact trajectory. The level-2 submodel codifies the relationship between inter-individual differences in the change trajectories and time-invariant characteristics of the individual. It is written in separate parts, one for each level-1 growth parameter. The level-2 submodel for equation (1) is thus:

$$\pi_{0i} = \gamma_{00} + \gamma_{01} X_{1i} + \gamma_{02} X_{2i} + \ldots + \gamma_{0p} X_{pi} + \zeta_{0i} \qquad (2)$$

$$\pi_{1i} = \gamma_{10} + \gamma_{11} X_{1i} + \gamma_{12} X_{2i} + \ldots + \gamma_{1p} X_{pi} + \zeta_{1i}$$

where X_{1i}, X_{2i}, …, X_{pi} are p predictors measured for subject i

$$\text{and} \begin{bmatrix} \zeta_{0i} \\ \zeta_{1i} \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_0^2 & \sigma_{01} \\ \sigma_{10} & \sigma_1^2 \end{bmatrix} \right)$$

The γ_{00}, γ_{0k}, γ_{10} and γ_{1k} parameters are known collectively as the fixed effects. They capture systematic inter-individual differences in change trajectory according to values of the level-2 predictors. γ_{00} and γ_{10} represent respectively the average intercept and average slope for individuals with level-2 predictor values of 0. γ_{0k} and γ_{1k} are respectively the average difference in intercept and the average difference in slope for a unit difference in X_k. Finally, the residuals, ζ_{0i} and ζ_{1i} represent the portion of the growth parameters that remains unexplained by the level-2 predictors. Their variances and covariance are denoted by σ_0^2, σ_1^2 and σ_{01}.

Parameters are estimated with the method of maximum likelihood and estimation can be done with SAS PROC MIXED. Estimates are unbiased for all types of ignorable non-response: missing completely at random (MCAR), covariate-dependent dropout (CDD) and missing at random (MAR). With repeated measures, MAR is present when non-response depends on previous measures performed on the subject. This type of non-response invalidates the results of many repeated measures analysis methods but is admissible with growth modeling.

2.2 Extensions of the linear model

The model can be extended to any polynomial trajectory of order n. It is thus written:

$$Y_{ij} = \pi_{0i} + \sum_{l=1}^{n} \pi_{li} T_{ij}^{l} + \varepsilon_{ij} \qquad (3)$$

$$\pi_{li} = \gamma_{l0} + \sum_{k=1}^{p} \gamma_{lk} X_{ki} + \zeta_{li}$$

The more complex the polynomial, the more waves of data you need to collect to be able to fit the trajectory to data. You need at least one more wave of data per person than there are individual growth parameters in the level-1 growth model. And these are only the minimum requirements. Greater precision and power require more waves. Discontinuous and non linear trajectories (logistic, hyperbolic, inverse polynomial, exponential …) can also be fitted.

2.3 The measurement of time

Choosing the scale for the temporal predictor is an important step in building the model. Many options are available. First, time can be represented by wave number. For example, if annual measurements are done for three years, the time variable would take the values 0 (baseline measurement), 1, 2 and 3. However, if measurement is done at discharge and three and twelve months after hospital discharge, the time variable would take the values 0, 3 and 12. This illustrates the fact that measurement occasions can be variably spaced, an advantage of growth models over repeated measures analysis of variance.

The number of days since the first assessment is a finer measure than wave number, allowing not only the occasions to be variably spaced, but also the number and spacing of measurement occasions to vary from one subject to another. Finally, the subject's age can also serve as a metric of time when one wants to study the evolution of a phenomenon with aging.

3. EXAMPLE

3.1 Data source

The data used for this example originate from the PRISMA Study (Program of Research to Integrate Services for the Maintenance of Autonomy). In this study, functional decline is studied in relation to the gradual implementation or not of an Integrated Services Delivery (ISD) system for frail elders experiencing functional decline. To constitute an ISD, mechanisms and tools are implemented to improve the integration and the continuity of care and services for frail elderly people.

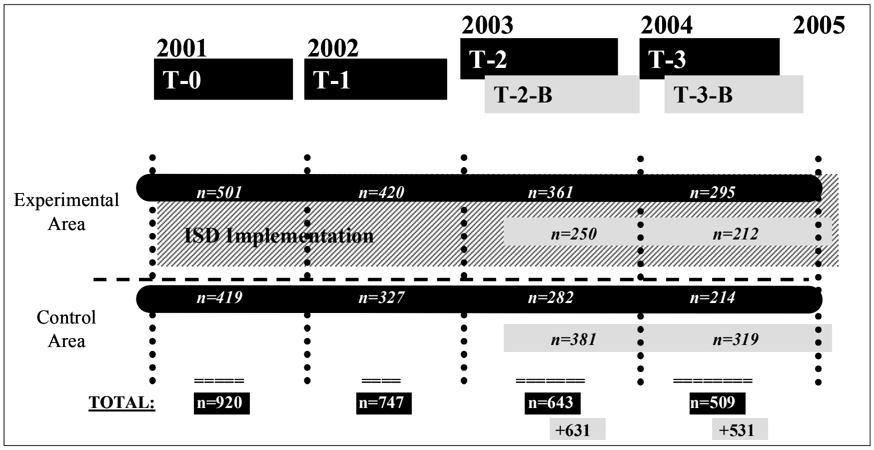
3.2 Study design

A quasi-experimental design with repeated measures allows us to make paired comparisons of three areas of the Eastern Townships (experimental area where an ISD is being implemented) to three comparable areas of Chaudière-Appalaches (control area): Sherbrooke with Lévis, Granit with Montmagny, Coaticook with L'Islet.

The sample is composed of people satisfying the following inclusion criteria : (i) aged 75 or over, (ii) living in the community, (iii) living in one of the study's six areas (iv) at risk for functional decline in the next year. A list of people satisfying the first three inclusion criteria was drawn using a simple random design from Québec's health care beneficiaries. This list constitutes an excellent sampling frame since health insurance is universal in Québec and thus all Quebecers are registered. Verification of the fourth inclusion criterion required sending a six-item postal questionnaire (Hébert et al, 1996) to all potential subjects. Older adults with three or more at-risk answers as well as those not returning the questionnaire constituted the sample and were contacted for enrollment. Not returning the questionnaire was shown to be a risk factor of functional decline. Two samples were selected in this manner, one in 2001 and the other in 2003. For the second recruitment phase, minimal age was 77 and the fact of having been chosen in 2001 became an exclusion criterion. During both recruitment phases, refusal to participate was not differential between the experimental and control groups.

Functional status was assessed at baseline then annually up to 2004 for all subjects still living in the community. Thus, subjects from the 2001 sample are assessed four times while those from the 2003 sample are measured twice. Figure 1 outlines the study methodology and reports sample sizes throughout follow-up.

Figure 1: Outline of the PRISMA Study



Functional status is assessed with the Functional Autonomy Measurement System (SMAF). The SMAF is a comprehensive scale that was developed according to the World Health Organization classification of impairments, disabilities, and handicaps (Hébert, 1982). It evaluates the person's ability to accomplish 29 functions covering five sectors of activity: activities of daily living (7 items), mobility (6 items), communication (3 items), mental functions (5 items), and instrumental activities of daily living (8 items). Each function is rated on a five-level ordinal scale: 0 (independent), -0.5 (independent but with difficulty), -1 (needs stimulation or supervision), -2 (needs help), -3 (dependent). It must be administered by a trained health professional with precise criteria based on information obtained by questioning the subject or a proxy, observing the subject or asking him/her to execute tasks. A total score, ranging from 0 (total independency) to -87 (total dependency) is obtained by summing scores obtained at each item. The metrological properties (reliability, validity and responsiveness) of the instrument are well established (Hébert et al, 1988; Desrosiers et al, 1995; Hébert et al, 2001).

3.3 The model

We choose a quadratic model to study functional decline. Let us recall that we are interested with the impact of ISD implementation on functional decline. Since the implementation of the various components of the ISD network occurs at fixed dates, it is relevant to study the change trajectories with reference to these dates rather than with regards to artificial wave numbers (0, 1, 2 , 3, 4) which occur at very different dates for each subject. Therefore, in our model, we choose to scale time with the number of days since January 1st 2001. At the model's second level, we assess the effect of area membership on the intercept, the instantaneous slope and the curvature of the trajectory. The model is thus:

$$\mathrm{SMAF}_{ij} = \pi_{0i} + \pi_{1i}(\mathrm{NB\ DAYS\ SINCE\ 01/01/01})_{ij} + \pi_{2i}(\mathrm{NB\ DAYS\ SINCE\ 01/01/01})_{ij}^{2} + \varepsilon_{ij} \qquad (4)$$

$$\pi_{0i} = \gamma_{00} + \gamma_{01}\mathrm{AREA}_i + \zeta_{0i}$$

$$\pi_{1i} = \gamma_{10} + \gamma_{11}\mathrm{AREA}_i + \zeta_{1i}$$

$$\pi_{2i} = \gamma_{20} + \gamma_{21}\mathrm{AREA}_i + \zeta_{2i}$$

3.4 Results

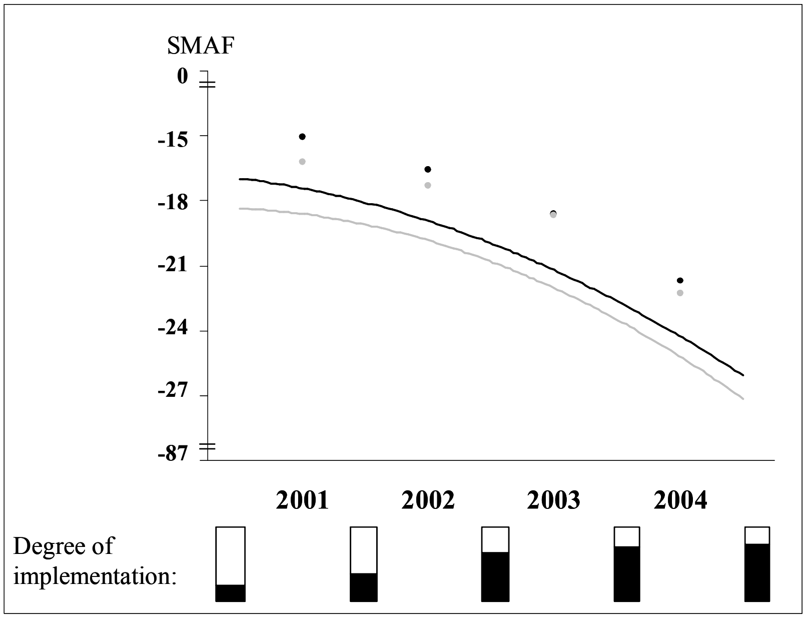
Table 1 presents parameter estimates for model (4) while Figure 2 illustrates the results. The trajectories obtained through growth modeling are contrasted to those obtained with classical repeated measures analysis of variance. Under the x-axis, the degree of implementation of the ISD (Hébert & Veil, 2004) is given, indicating the percentage of implementation of the ISD in the experimental area in the middle of each year. Thus, up to now, functional decline follows the same trajectory in both areas, maybe because ISD implementation is not completed in the Eastern Townships. Interestingly, although classical repeated measures analysis of variance based on survivors also shows a similar functional decline for both areas, they systematically underestimate the level of functional status. This is not surprising given that subjects excluded from these analyses are those who died or were institutionalized during follow-up, these subjects being among the frailest at baseline.

Table 1: Results from fitting a growth model to the PRISMA data

		Parameter	Initial Model	Setting ζ_{2i}=0
Fixed Effects				
Initial status, π_{0i}	Intercept	γ_{00}	16.95***	16.96***
	Control area	γ_{01}	1.38~	1.38~
Initial slope, π_{1i}	Intercept	γ_{10}	0.79*	0.73*
	Control area	γ_{11}	-0.46	-0.47
Curvature, π_{2i}	Intercept	γ_{20}	0.36***	0.39***
	Control area	γ_{21}	0.10	0.10
Variance components				
Level 1	Within-person	σ^2_ε	14.64***	15.85***
Level 2	In initial status	σ^2_0	124.26***	127.84***
	Linear term			
	variance	σ^2_1	11.72**	6.35***
	covar with initial status	σ_{01}	4.42	0.95
	Quadratic term			
	variance	σ^2_2	0.39~	
	covar with initial status	σ_{02}	-1.13	
	covar with linear term	σ_{12}	-1.40	

~ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$

Figure 2: Functional decline during follow-up by area: experimental (in black) or control (in grey) and type of analysis: growth model (solid lines) or repeated measures ANOVA (dots)



4. DISCUSSION

Growth models have numerous advantages for the study of the evolution of changes in the health status of the elderly. They allow a substantial reduction in bias for all types of ignorable non-response. The missing at random (MAR) assumption is plausible here since death or institutionalization are often related to previous measures of health status. In addition, the model makes it possible to maintain the desired statistical power since it allows adding subjects at the different evaluation waves. Other characteristics of the model make it interesting, namely the fact that measurement occasions can be variably spaced, the number and spacing of measurement occasions can vary from one subject to another and time can be treated flexibly (wave number, calendar date, age). In addition, there are many possibilities to model change (linear, quadratic, logistic …) depending on the number of waves of measurement per subject. Finally, another advantage not discussed in this article, is that time-varying predictors can be included in the level-1 model.

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