National Study of Health and Growth: effect of change in design with reference to efficiency of mixed longitudinal studies for measuring trends

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Keywords: longitudinal studies, population surveillance, efficiency, trends

Paper read to Section of Epidemiology & Community Medicine, 13 March 1986

Summary

The National Study of Health and Growth (NSHG) is a surveillance system which monitors the growth of primary school children in England and Scotland, set up in 1972 following changes in the school milk and welfare system. However, the study contained few children from inner city areas or ethnic minorities. In 1982 its design was changed from one in which the same areas were surveyed every year, to two separate systems with areas surveyed every two years, one set of areas corresponding to those in the original study, and the other set consisting of inner city and ethnic minority areas. The precision of the estimates of trends in height and weight for each system was smaller than that of the original system, but by less than 50%, so that an overall gain in information was achieved. Studies of mixed longitudinal design are shown also to be generally, but not always, less efficient for estimating trends than independent cross-sectional surveys obtaining the same number of measurements.

Introduction

Following changes in the provision of welfare milk, school milk and school meals in 1971, studies were set up to assess the possible effects of these upon the nutritional state of the population[1]. The aim of the National Study of Health and Growth (NSHG)[2,3] was to set up an anthropometric system of surveillance on selected growth, nutritional and health characteristics that would identify the effects of changes in food policy. Height was chosen as the main indicator of nutritional status and has been measured, together with weight and triceps skinfold thickness, for around 10 000 primary school children each year in England and Scotland. In the original design[3], 22 areas in England and 6 in Scotland were selected. Each child attending the selected schools in these areas at the time of survey was eligible for measurement, so that a child remaining at the same primary school could be measured seven times from age 5 to 11 years. However, a substantial number of children move in or out of a school catchment area during primary school ages, so that the number of measurements for each child varies from one to seven. The design is thus complex mixed longitudinal, the follow-up or longitudinal element varying from one to seven years, and children measured once only contributing a cross-sectional element.

The primary aim of the NSHG is to estimate trends in anthropometric measurements for children of the same age. Although changes in rate of growth at a given age may occur over time, the main question is whether there has been any overall shift in the position of the growth curve. Trends in height have been published[4] for the period 1972 to 1980, and many analyses of data from one year (cross-sectional) and limited follow-up analyses have been carried out, for example of rate of growth in relation to free school milk[5] and school meals[6]. These analyses revealed the smaller number of children in the study that could be considered deprived, despite the weighting of the original sample towards poorer areas. Only one area contained more than a few children from ethnic minority groups.

A parallel surveillance system was introduced for children in inner city areas and in areas with a high proportion of immigrants from the West Indies, Africa or Indian subcontinent. In order to introduce this second system at no extra monetary cost, the frequency of visits to the original areas was reduced to each alternate year, with the newly selected areas being visited in the intervening years. Inevitably the precision of the estimates of trends for the original areas was reduced, due to less data. This paper quantifies the reduction in precision, that is the increase in the variance of the estimates of trend, resulting from the change in the frequency of survey. The main comparison is that of one system of the new design with the original. In addition, the efficiency of the mixed longitudinal study is compared with a series of independent cross-sectional studies. The methods are applicable to the design of any surveillance study in which trends in continuous measurements are to be estimated.

Method

Because the data have a mixed longitudinal structure, the calculation of the change in precision is complex. Details of the original design and the method of estimation of trends are given by Chinn and Rona[4]. The method of estimation was based on that of van't Hof *et al.*[7] For the estimation of an overall linear trend in height, the heights for each cohort at each year of measurement were first averaged. Then for each age an estimate of linear trend in height was found by regressing mean height on cohort, to give seven estimates of trend, which were then averaged to give an overall estimate.

The same method of estimation is applicable to each system of the new design, in which each provides a maximum of three or four height means for each cohort, instead of seven in the original design.

As each regression coefficient is a linear combination of the mean heights, with predetermined coefficients, so is the final estimate, and hence its

0141-0768/87/090544-03/$02.00/0

variance is a known linear combination of the variance and covariances of the mean heights. The latter depend on a number of quantities; by varying those that are determined by the design of the study, the effect of different designs on the efficiency of trend estimates can be calculated. The variance of mean height is determined by the between-child variance of height and the number of heights averaged. The covariance of any two mean heights is zero if the means are for different cohorts, but positive for two means for the same cohort and dependent on the correlation between individual measurements and the proportion of children measured on both occasions. The correlation and the proportion of children remeasured decrease as the time gap between measurements increases.

It is assumed that the number of children measured at any survey, and in each age group, is constant, and that the between-child variance is constant. The variance of height increases with age, but the assumption is not crucial to the comparison of designs with age groups equally represented. The correlation of measurements taken j years apart is assumed to be ρ^j, and the proportion of children remeasured after j years π^j, a proportion $1-\pi$ being lost to follow up each year. The formulae used to calculate the estimate of trend and its variance are given in the Appendix. Results are expressed as relative efficiency of one design to another, the ratio of the variance of the estimate from the latter to that from the former, so that relative efficiency is less than one if the estimate from the first design has the greater variance.

The proportion of subjects followed up in the mixed longitudinal designs was assumed to be 0.9 for surveys one year apart, and thus 0.9^2 ($=0.81$) for surveys two years apart, the proportion being appropriate for the original area selection in the NSHG. Seven age groups were considered.

Results

Column (*a*) of Table 1 shows that the relative efficiency of surveys every two years compared to a study each year is well above 0.5, although the number of measurements is halved. For a given correlation between individual measurements, the relative efficiency increases with the number of years of study. It decreases as the correlation decreases. Compared to independent cross-sectional surveys, equivalent to an assumption of no subjects remeasured, column (*b*) shows that the efficiency for a small number of surveys is greater than one. For ten years of study, that is five surveys, the relative efficiency increases as the correlation decreases.

Discussion

When the design of the NSHG was changed, it was recognized that there would be some loss in efficiency for the estimation of trends for the original areas, but the overriding concern was to establish the second surveillance system for the inner city areas and ethnic minorities. As height has a very high correlation, about 0.99, between measurements one year apart, and the majority of the 'lost' measurements in the new design are additional measurements on the same children, it was not expected that the loss of efficiency for estimation of trends in height would be great. This has been borne out by the results, which show an efficiency of one system of the new design relative to the old of 0.90 over a ten-year period. For weight, with correlation about 0.9 on a log scale, the relative efficiency is 0.85.

Rather surprising was the efficiency of the mixed longitudinal design relative to independent cross-sectional surveys. It might be expected, particularly for height, that the correlation between means in the mixed longitudinal design would lead to low efficiency compared to the uncorrelated means in the cross-sectional design. However, the relative efficiency is greater than one when there are only three surveys with two-year time gaps. As the number of surveys increases, the efficiency of the mixed longitudinal design decreases relative to the cross-sectional design.

In respect of the number of age groups and the proportion of subjects followed up, we have given only figures relevant to the NSHG. Fewer age groups would reduce the number of times a subject could be remeasured and hence, in general, increase the efficiency of the mixed longitudinal design relative to cross-sectional surveys. Reducing the proportion of subjects followed up would in general increase the relative efficiency, as the limit, no subjects followed up, is equivalent to the cross-sectional design. However, results were not always in line with intuitive

Table 1. Efficiency of mixed longitudinal surveys every two years compared to every year, and to independent cross-sectional surveys every two years, for the estimation of linear trend averaged over seven age groups

Correlation between measurements one year apart	*Proportion of subjects remeasured after one year*	*Period of study (years)*	*Efficiency of survey every two years compared to*	
			(a) Survey each year	*(b) Independent cross-sectional surveys every two years*
0.99	0.9	6	0.79	1.37
		8	0.86	0.95
		10	0.90	0.74
0.90	0.9	6	0.76	1.23
		8	0.83	0.92
		10	0.85	0.77
0.80	0.9	6	0.73	1.13
		8	0.81	0.91
		10	0.84	0.80
0.50	0.9	6	0.63	1.02
		8	0.70	0.94
		10	0.73	0.90

expectation, so exact calculation is recommended for designs under consideration.

It must be emphasized that these results apply only to the estimation of linear trends over time in the population, and not to changes in individuals. Mean rate of growth, for example, which can be estimated from cross-sectional surveys, is more efficiently estimated from a pure longitudinal study[8]. A design that is efficient for one purpose will often be inefficient for another, and a choice made based on appropriate calculations. Choice of design should not be made solely on grounds of statistical efficiency, especially as costs may not be proportional to the number of measurements.

The NSHG now has two separate surveillance systems, one for the original randomly selected areas, and the other for the inner city and ethnic minority areas. The results have shown the efficiency of the first to be more than half that of the original design for the measurement of trends, and as high as 0.9 for height over a ten-year period. Little information has been lost, and the second system gained. Of the children who entered the second system in 1983, the proportion followed up in 1985 was about 0.80, similar to the two year follow-up for the first system. The second system, therefore, has an efficiency similar to the first for the estimation of trends, and overall the new design has resulted in a substantial gain in information.

Acknowledgments: We thank Professor W W Holland for his continued encouragement. The National Study of Health and Growth is supported by the Department of Health and Social Security and the Scottish Home and Health Department.

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APPENDIX

Notation

g	number of age groups
k	number of surveys
t	time gap between surveys
σ^2	between-subject variance
n	number of subjects per survey and age group
ρ	correlation between measurements for $t=1$
π	proportion of subjects followed up for $t=1$
$\bar{y}_{ij}$	measurement mean for ith survey, jth age group

Estimate of trend b_j for one age group

$$= \frac{12}{t^2k(k^2-1)} \sum_{i=1}^{k} \bar{y}_{ij} \left[it - \left(\frac{k+1}{2}\right) t \right]$$

Overall estimate

$$= \frac{12}{gt^2k(k^2-1)} \sum_{j=i}^{g} \sum_{i=1}^{k} \bar{y}_{ij} \left[it - \left(\frac{k+1}{2}\right) t \right]$$

Variance of estimate

$$= \frac{144\sigma^2}{ng^2t^4k^2(k^2-1)^2} \sum_{\text{cohorts}} \sum_{i} \sum_{l} \left(it - \left(\frac{k+1}{2}\right) t \right) \left(lt - \left(\frac{k+1}{2}\right) \right) \rho^{|(i-l)t|} \pi^{|(i-l)t|}$$

All surveys including cohort

(Accepted 11 November 1986)