Household surveys of health in developing countries are carried out frequently to estimate burden of disease, attitudes to health care, use of health services, and coverage of interventions. These surveys are often undertaken by teams from health ministries, disease control programmes or non-governmental agencies with limited resources, without specialized sampling skills, and without the use of a comprehensive and up-to-date sampling frame of people or households.

The World Health Organization’s Expanded Program on Immunization (EPI) first recognized the need to carry out an approximately valid sample survey in such a situation. The EPI ‘30 × 7’ cluster survey method was developed to meet the needs of health managers for reliable estimates of vaccine coverage. It has been used for thousands of such surveys, and, with or without adaptation, for many other purposes. The method is standardized, quick to implement, and approximately self-weighting (and therefore simple to analyse), but it has important limitations. Firstly, communities are selected with probability proportional to size (pps) according to the most recent census data, but these data can be inaccurate and out of date, particularly with respect to fast-growing peri-urban areas. This will often mean that such areas, which may have the poorest access to health care, will be under-represented in the sample, and the overall estimate of vaccine coverage will be biased upwards. Secondly, the method does not select households from a sampling frame, but instructs the interviewer to follow a random procedure in the field, resulting in a cluster of households being selected within the community.
This procedure is open to conscious or unconscious bias of the interviewer, and does not lead to a sample selected with known probability. Thirdly, in case of non-response, one simply goes on to select the next household, leading to bias if non-responders differ systematically from those who do participate.

The EPI methodology has sometimes been adopted for purposes other than vaccine coverage, in situations where the sample size (30 clusters of 7 children) and the method of household selection (based on children aged 12–23 months) are quite inappropriate. Bennett et al. presented a number of extensions and adaptations of the EPI approach, including alternative household selection methods and appropriate sample size and analysis methods, retaining its simplicity while extending its applicability. However, this did not adequately address the problems of outdated population estimates and possible subjectivity in household selection mentioned above.

More recently, Turner and colleagues have proposed an improved cluster sampling method for resource-poor situations without a household sampling frame, which, by segmenting clusters and visiting all households in one randomly chosen segment, allows objective selection of households, sampling probabilities to be calculated, and non-responders to be revisited without resort to the cost of complete enumeration. A further potential advantage of this method is that, since all selections are made with known probability, population totals may be estimated, which may be useful for resource planning.

The EPI method and its adaptations have been evaluated for precision and possible bias by computer simulation. Bennett et al. presented a number of countries in the UNICEF Multiple Indicator Cluster Surveys, however, we were unable to find any published data comparing their use in the same field situation. We used both methods in separate surveys to measure childhood vaccination coverage in the same region of The Gambia at approximately the same time. In this paper we describe the design and analysis and compare the results of the two approaches. We also predict under a simplified mathematical model the situations in which the EPI method will exhibit substantial bias.

Methods

The EPI method

In the EPI method, 30 communities (clusters) are selected with probability proportional to the most recent census estimate of the community population size, by systematic selection from a list of cumulative population sizes. In each selected cluster, the interview team starts at a central point, selects a random direction from that point, and chooses a dwelling at random among those along the line from the centre to the edge of the community. All children in the household in the age range 12–23 months are selected and the mother or caregiver interviewed (all households are visited in a multi-household dwelling). Starting from this household, the next nearest household is visited in turn until at least seven children have been found. In case of non-response, call-backs are not usually implemented, the interviewers proceed to the next household. Since clusters are selected with probability proportional to estimated size (pops), households are selected with approximately equal (but unknown) probability, and all eligible children in a household are selected, the overall probability of any child being selected is roughly equal, and the design is approximately self-weighting (no weighting is needed in the analysis). The sample size allows vaccine coverage to be estimated with a 95% CI of ±10 percentage points, on the assumption of a design effect (increase in variance due to clustering) of 2. If the region to be surveyed is very large, or heterogeneous, it may be split into strata and 30 clusters selected from each stratum, allowing subregional estimates to be made.

Compact segment sampling

In compact segment sampling, clusters are still selected with probability proportional to size at the last census. A sketch map is then drawn of each selected cluster, showing dwellings, and the cluster is then split into a small number of segments, such that the number of dwellings per segment is always roughly the same. One segment is then chosen at random from each community and all households in the segment are included in the sample. This method removes the subjectivity and possible bias inherent in allowing the interviewer to select households in the field. It also facilitates calling back at those households where there is no, or incomplete, response. Kish gives detailed practical guidance. Turner et al. claim that this design is self-weighting, allowing easy changes in cluster population since the last census. This is only true if the census is up to date. Using their notation, if \( M_i \) is the total population of all clusters in the sampling frame, \( m \) the number of clusters selected in the survey and \( S_i \) the number of segments created in the \( i \)th cluster, then the probability of selection of any household in the \( i \)th cluster is

\[
P_i = m \times (M_i/M) \times (1/S_i)
\]

The survey is self-weighting if the \( P_i \) are the same for all \( i \), which will be true if the number of households per segment, \( M_i/S_i \), is constant across clusters. Since \( S_i \) is chosen on the basis not of \( M_i \) but of \( N_i \), the present number of households in the cluster, this will only be even approximately true if \( N_i \) is proportional to \( M_i \) across clusters, that is if all clusters have grown at approximately the same rate since the census (in which case, even the EPI method does not need weighting). Thus in general the analysis of the compact segment sampling method requires that data from the \( i \)th cluster be weighted by \( 1/P_i \), the inverse of the probability of selection. This is the number of children in the population that each sampled child represents. Weighting compensates for inaccuracies in the census, discrepancies between the distribution of households (the measure of size) and distribution of children (the population of inference), and changes in the population distribution since the census. It is undesirable to choose the number of segments on the basis of estimated size \( (M_i) \), because this does not permit an efficient distribution of field workload. Updated measures of size extrapolated from the most recent census can be used but are usually based on average growth rates and therefore do not reflect uneven growth.

Our surveys

In November 2000 to January 2001 we undertook a survey of vaccination coverage in the Western Region of The Gambia using the compact segment method, as part of a study to evaluate the introduction of Haemophilus influenzae type b (Hib)
vaccine into the country's immunization schedule. In February 2001, the Ministry of Health carried out their routine survey using the EPI method.

**Study area**

Approximately half of the population of The Gambia (just over 1 million in 1993) live in Western Region, which includes the capital Banjul, rapidly growing urban areas of Kanifing and Brikama, as well as rural areas (Figure 1). The average annual growth rate between the 1983 and 1993 censuses was 6% in urban areas and 3% in rural areas\(^9\) (Table 1).

National immunization coverage for children under one year was estimated to be over 80% in 1999 but there are believed to be pockets of low coverage in urban and periurban areas where population growth is rapid and health services are more stretched. In one urban area in Western Division surveyed in 1999, coverage of full vaccination in under-ones was 50%.\(^10\)

**First survey, using compact segments: sample size and planning**

The most recent census (1993) defined 909 enumeration areas (EA) of median population 617 (range: 208–2779) in Western Region, with a total population of 574,026. The median number of households per EA was 76 (range: 2–348) and the median household size was 8 (range: 1–79). We estimated that by the time of our survey there would be an average of 26 to 28 12–23 month old children per EA.

We were primarily interested in the coverage of the jointly administered diphtheria-pertussis-tetanus (DPT) and Hib vaccines. The total number of children required\(^2\) is given by

\[
\text{deff} \times \frac{z_{1-\alpha/2}^2}{\pi (1-p)} \times d^2
\]

where \(p\) is the proportion of children vaccinated, \(d\) the desired margin of error, \(z_{1-\alpha/2}\) the \(1 - \alpha/2\) percentage point of a standard normal distribution and \(\text{deff}\) the design effect, the loss of information (increase in variance) in the sample due to the clustering of observations. The value of \(\text{deff}\) increases with increasing cluster size, according to the relationship\(^10\)

\[
\text{deff} = 1 + [(b - 1) \times \text{roh}],
\]

where \(b\) is the average number of individuals sampled in each cluster and \(\text{roh}\) is the rate of homogeneity, which can range from just less than zero up to 1. We took \(\text{roh}\) to be 0.15, typical of values seen for immunization coverage.\(^2,12\)

If we segmented EA to give a cluster size of about 40 households, we would expect to find 14 children in each cluster, and 60 clusters could be completed in the time available. This gave a predicted design effect of 2.95, and an expected sample size of 60 \(\times 14 = 840\), which would give an estimate of vaccination coverage within \(\pm 6\%\) of the true value if the coverage was 50%, and within \(\pm 5\%\) if the coverage was 80%.

**First survey, using compact segments: sample selection**

EA were selected with probability proportional to the number of households recorded in the 1993 census. Small EA were grouped with adjacent larger EA before selection. In all, 60 EA were selected systematically, yielding an implicit geographical stratification. In a preliminary exercise, each selected EA was sketch-mapped to show the location of each compound (a multi-household dwelling, frequently housing an extended family). In each compound, we determined the number of households and

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**Figure 1** Map of the study area (shaded) showing population distribution in 1993. Vaccination is delivered through 20 health centres and their outreach stations (not shown).

**Table 1** Urban and rural population growth in the study area\(^11\)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Banjul</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>urban</td>
<td>39,476</td>
<td>44,188</td>
<td>42,326</td>
<td>−0.4%</td>
</tr>
<tr>
<td>Western Division</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>urban</td>
<td>48,417</td>
<td>121,128</td>
<td>269,975</td>
<td>8.0%</td>
</tr>
<tr>
<td>rural</td>
<td>82,000</td>
<td>117,621</td>
<td>192,033</td>
<td>4.9%</td>
</tr>
<tr>
<td>North Bank west</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>urban</td>
<td>2,154</td>
<td>4,554</td>
<td>8,743</td>
<td>6.5%</td>
</tr>
<tr>
<td>rural</td>
<td>39,242</td>
<td>44,098</td>
<td>60,949</td>
<td>3.2%</td>
</tr>
<tr>
<td>Total</td>
<td>211,289</td>
<td>331,589</td>
<td>574,026</td>
<td>5.5%</td>
</tr>
</tbody>
</table>
made a rough estimate of the number of resident children aged 12–23 months. The latter was not essential and added significantly to the workload, but allowed us to reduce the variability in the number of children per segment.

Maps were returned to the office for segmenting. For each EA, we calculated the number of segments by dividing the estimated number of children aged 12–23 years in that EA by 14 and rounding to the nearest integer. Segments were defined using natural boundaries (roads, rivers) and avoiding splitting blocks of compounds where possible. If the estimated number of children in an EA was less than 14, all households in the EA were included in the survey. The median number of segments per EA was 2 (range: 1–12). One segment was selected from each selected EA by simple random sampling, and marked clearly on the map.

The interviewer teams returned to the area and visited each household in the selected segment. Age was confirmed from the health card and, for each child aged 12–23 months on 20 December 2000, vaccination, date of birth, and other details were transcribed from the card. If the health card was missing or illegible, and, for each child aged 12–23 months on 20 December 2000, vaccination, date of birth, and other details were transcribed from the card. If the health card was missing or illegible, and for each child aged 12–23 months on 20 December 2000, vaccination, date of birth, and other details were transcribed from the card.

The estimated number of children in an EA was 2 (range: 1–12). One segment was selected from each selected EA by simple random sampling, and marked clearly on the map.

**Second survey, using EPI method**

A nationwide survey was conducted in seven strata, three of which (Banjul, Western Division, and North Bank West) comprised Western Region. Within each stratum, 30 settlements (villages) were selected with probability proportional to the 1993 estimates of the number of households. The same personnel conducted these surveys in February 2001. In all, seven or eight children aged 12–23 months were selected in each cluster as described in the section on ‘The EPI method’ above, but using a random start point obtained from the list of local tax-payers. Only children with health cards were included in the survey.

**Analysis of data**

For any sampling scheme, both the number of children vaccinated and the number of children selected in a cluster are random variables, thus the proportion of children vaccinated is a ratio of random variables. The total number of vaccinated children in the region, \( Y \), and the current total number of children in the region, \( N \), are estimated by weighting each observation by \( 1/P_i \):

\[
\hat{Y} = \frac{\sum y_i}{P_i} \quad \text{and} \quad \hat{N} = \frac{\sum n_i}{P_i}
\]

respectively, where \( n_i \) is the number of children surveyed in the \( i \)th EA, and \( y_i \) the number of these that had been vaccinated. The estimate of the proportion of children vaccinated (the coverage) in the region is then the ratio of these:

\[
\hat{R} = \frac{\sum (y_i/P_i)}{\sum (n_i/P_i)}
\]  

(2)

In a self-weighting survey, all the \( P_i \) are equal to the same value, \( P \). The formulae for totals simplify in an obvious way, and the \( P_i \) cancel completely in equation 2. Note that the EPI scheme is approximately self-weighting, but the value of \( P \) is unknown, so that the totals cannot be estimated.

The variance of the estimated coverage can be estimated by:

\[
\hat{V}(\hat{R}) = \frac{\hat{N}}{[\hat{N}(\hat{N} - 1)]} \sum_{i=1}^{m} \left( \frac{1}{n_i} - \frac{1}{\hat{N}} \right)^2 \hat{R}_i^2 \]

(3)

In the EPI method, an implicit assumption is that the random walk procedure approximates an equal probability selection of children, the probability of selection being

\[
P_i = m \times (M_i/M) \times (n_i/N_i)
\]

where \( n \) is the (approximately) constant number of children surveyed per cluster and \( N_i \) represents the (unknown) current total number of children in the \( i \)th cluster. The method ignores uneven population growth since the last census, assuming that the ratio \( N_i/M_i \) is a constant equal to \( N/M \) so that \( P_i = m n_i/N \) and the variance formula (equation 3) simplifies to:

\[
\hat{V}(\hat{R}) = \frac{1}{[m(m-1)]} \sum_{i=1}^{m} \left( \frac{1}{n_i} - \hat{R} \right)^2
\]

(4)

where \( \hat{R} = \sum_{i=1}^{m} y_i / \sum_{i=1}^{m} n_i \).

A 100(1 – α)% CI is given by \( \hat{R} \pm t_{1-\alpha/2,m-1} \sqrt{\hat{V}(\hat{R})} \).

The design effect may be estimated as:

\[
\text{deff} = \frac{\hat{V}(\hat{R})}{\hat{V}(\hat{R})}
\]

where \( \hat{V}(\hat{R}) = \hat{R}(1 - \hat{R}) \left( \sum_{i=1}^{m} n_i - 1 \right) \) is the estimated variance under simple random sampling.

The variance of the estimated total number of children, \( \hat{N} \), is estimated by:

\[
\hat{V}(\hat{N}) = \frac{1}{m(m-1)} \sum_{i=1}^{m} \left( \frac{n_i}{P_i} - (\hat{N}m) \right)^2
\]

(5)

Variance estimates using these formulae do not take account of the possible gain in precision from the implicit stratification achieved by systematic sampling from geographically ordered lists of EA, and therefore they may be conservative. Details of stratified surveys, and examples of analyses in Stata, are available from the authors.

**Predicted bias of EPI sampling**

Using data from the surveys, we can predict mathematically the expected bias in EPI sampling due to not weighting for uneven population growth (the weighted segment method is unbiased). We neglect other sources of bias (e.g. non-random sampling) and make the simplifying assumption that at the time of the census all clusters were the same size and had the same number of children, \( N_o \) so that we have simple random sampling of clusters. The expected bias is \( E(\hat{R}_{EPI}) - \hat{R} \), where \( \hat{R}_{EPI} \) is the point estimate of coverage from EPI sampling and \( \hat{R} \) is the true population coverage. Taking expectations over all possible samples for the EPI method, we have:

\[
E(\hat{R}_{EPI}) = E \left( \frac{1}{m} \sum_{i=1}^{m} \frac{y_i}{n_i} \right) = \frac{1}{m} \sum_{i=1}^{m} P_i = \hat{p}
\]
where \( m \) is the number of clusters surveyed, \( C \) is the number of clusters in the whole population, \( y_i \) is the number of vaccinated children in cluster \( i \) out of a sample of \( n_i \), \( p_i \) is the true proportion vaccinated in cluster \( i \) and \( p \) is the population mean of the \( p_i \). If we define the quantity \( g_i \) to be the factor by which the \( i^{th} \) cluster has grown since the census (so that the current population is \( N_0 g_i \)), then the true population prevalence is given by

\[
R = \frac{1}{n} \sum_{i=1}^{n} \frac{y_i}{n_i} = \frac{1}{C} \sum_{i=1}^{C} \frac{g_i p_i}{g_i p} = \frac{1}{C} \sum_{i=1}^{C} \frac{g_i}{g}
\]

where \( g \) is the population mean of the \( g_i \). The bias is then

\[
p - \frac{1}{C} \sum_{i=1}^{C} g_i p_i / C g.
\]

Defining \( \rho_{g,p} \) to be the correlation between \( p_i \) and \( g_i \) in the population, \([E(pg) - \bar{p} \bar{g}] / \sqrt{V(p)V(g)}\), where \( V(p) \) and \( V(g) \) are the variances of \( p \) and \( g \) respectively, we see that the bias is equal to

\[
-\rho_{g,p} \sqrt{V(g)V(p)}/\bar{g}.
\]

### Results

Mapping for the first survey (using compact segments) showed that the number of households had increased by 53% since 1993, with dramatic increases in some EA on the periphery of the urban areas (Table 2). 828 children were surveyed, 790 (95%) had completed health cards, 3 had replacement blank cards, 1 had an unreadable card, and 34 had missing cards. Results including interview data from mothers whose cards were missing or unusable were very similar to those for card only; card-only results are presented as these can be compared with EPI survey results. The average number of children sampled per cluster was 13.5 (range: 5–26, coefficient of variation (CV) 0.34). In the second survey (using the EPI method) 671 children were surveyed. The 1993 population was used as weight for combining the results from the three strata.

Data were missing for two clusters in one stratum (Banjul); since this stratum had a low weighting (Table 1) this is unlikely to have caused appreciable bias.

Both methods gave very similar point estimates of vaccination coverage in Western Region (Table 3) and point estimates from the segmentation method were similar whether or not the observations were weighted. The estimates of the proportion fully vaccinated were 0.56 (EPI) and 0.54 (weighted or unweighted segmentation method). The estimated coverage of three doses of DPT/Hib was 0.68 by all methods. The difference between the estimates from the two methods was rarely more than 2% (Figure 2). Interestingly, the difference (EPI-segment) was inversely correlated with the level of coverage (\( r = -0.56 \), \( P = 0.03 \)). Coverage of oral polio vaccine (OPV4) was higher in the second survey, this may reflect activities of the polio eradication campaign that took place between the two surveys.

Vaccination coverage was low in areas of rapid population growth. The correlation between the proportion of children who had received three doses of DPT/Hib in each EA, and population growth estimated as the ratio of the number of households in 2000 to the number in the 1993 census, was \( r = -0.28 \); \( P = 0.03 \) (Figure 3). A consequence of this was that design effect estimates were often higher using weighted than unweighted segment sampling (Table 4a). Design effect estimates for DPT/Hib were high, reflecting patchy availability of Hib vaccine since its introduction. Design effect estimates for EPI sampling were inflated by the effect of stratum weighting; for comparative purposes we therefore computed design effects for EPI sampling without stratum weights (Table 4a). The smaller number of children per cluster in the EPI scheme means that, while the design effects may be similar to those for segment sampling, the rate of homogeneity (roh) estimates are considerably higher than in the unweighted segmented scheme (Table 4b).

Estimates of the total number of children aged 12–23 months in the region are available from the first survey and can be used to estimate vaccine supply requirements. There are an estimated 22,960 children aged 12–23 months in the region, slightly lower than projected from the 1993 census. Using

### Table 2  Enumeration Areas (EA) showing minimum, median, and maximum population growth since 1993 census

<table>
<thead>
<tr>
<th>EA name</th>
<th>Settlement</th>
<th>No. of households in 1993, ( M_i )</th>
<th>No. of households in 2001</th>
<th>% Increase in no. of households 1993–2001</th>
<th>Estimated no. of children aged 12–23 months in 2001</th>
<th>No. of segments, ( S_j )</th>
<th>No. children surveyed</th>
<th>Weight = ((S_j \times (72 \times 0.03)) / (60 \times M_i))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50–052</td>
<td>KERR OMAR</td>
<td>41</td>
<td>27</td>
<td>-34</td>
<td>14</td>
<td>1</td>
<td>12</td>
<td>29.3</td>
</tr>
<tr>
<td></td>
<td>JAWARA</td>
<td>91</td>
<td>67</td>
<td>-26</td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>13.2</td>
</tr>
<tr>
<td>11–020</td>
<td>BANJUL CENTRAL</td>
<td>106</td>
<td>81</td>
<td>-24</td>
<td>12</td>
<td>1</td>
<td>8</td>
<td>11.33</td>
</tr>
<tr>
<td>12–034</td>
<td>BANJUL SOUTH</td>
<td>65</td>
<td>82</td>
<td>26</td>
<td>27</td>
<td>2</td>
<td>16</td>
<td>36.96</td>
</tr>
<tr>
<td>Median</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30–116</td>
<td>MANDINARING</td>
<td>266</td>
<td>337</td>
<td>27</td>
<td>52</td>
<td>3</td>
<td>11</td>
<td>13.55</td>
</tr>
<tr>
<td>20–171</td>
<td>NEW JESHWANG</td>
<td>96</td>
<td>287</td>
<td>199</td>
<td>64</td>
<td>4</td>
<td>11</td>
<td>50.05</td>
</tr>
<tr>
<td>20–230</td>
<td>BAKOTEH</td>
<td>348</td>
<td>1084</td>
<td>211</td>
<td>244</td>
<td>12</td>
<td>19</td>
<td>41.42</td>
</tr>
<tr>
<td>20–061</td>
<td>KOTU</td>
<td>107</td>
<td>410</td>
<td>283</td>
<td>113</td>
<td>7</td>
<td>21</td>
<td>78.58</td>
</tr>
<tr>
<td>20–316</td>
<td>TALINDING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
estimated coverage of one, two, and three doses of DPT/Hib of 0.94, 0.84, and 0.68, we estimate that at least \(22,960 \times (3 - 0.94 - 0.84 - 0.68) = 12,398\) more doses of DPT/Hib need to be delivered per year to bring coverage of three doses up to 100%, an 18% increase.

Using equation (6) and data from these surveys, we can model the potential bias of the EPI method. We use the number of households as a measure of population size (and neglect the effects of variation among EA in the number of children per household). From our data we had \(p = -0.28\) for three doses of DPT/Hib. The observed sample variance of cluster-level coverage of three doses of DPT/Hib was \(\approx 0.05\) and the population variance was estimated from this by subtracting an estimate of the within-cluster variance\(^{14}\) as \(V(p) = 0.03\). The coefficient of variation of the proportionate increase in population (estimated for each EA from the number of
Table 4 Estimates of design effect (deff) and rate of homogeneity* (roh) for the two sampling methods (m = number of clusters)

(a) Design effect estimates:

<table>
<thead>
<tr>
<th>Vaccine</th>
<th>Segment sampling, weighted (m = 60)</th>
<th>Segment sampling, unweighted (m = 60)</th>
<th>EPI* method, (m = 88)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCGb</td>
<td>1.20</td>
<td>0.88</td>
<td>1.58</td>
</tr>
<tr>
<td>Hep1f</td>
<td>1.00</td>
<td>1.21</td>
<td>1.09</td>
</tr>
<tr>
<td>Hep2</td>
<td>4.47</td>
<td>1.59</td>
<td>1.35</td>
</tr>
<tr>
<td>Hep3</td>
<td>2.37</td>
<td>1.40</td>
<td>1.03</td>
</tr>
<tr>
<td>OPV0d</td>
<td>1.07</td>
<td>1.07</td>
<td>1.13</td>
</tr>
<tr>
<td>OPV1</td>
<td>1.53</td>
<td>1.32</td>
<td>1.59</td>
</tr>
<tr>
<td>OPV2</td>
<td>1.25</td>
<td>1.32</td>
<td>1.45</td>
</tr>
<tr>
<td>OPV3</td>
<td>3.09</td>
<td>1.83</td>
<td>1.43</td>
</tr>
<tr>
<td>OPV4</td>
<td>1.40</td>
<td>1.43</td>
<td>1.57</td>
</tr>
<tr>
<td>DPT/Hib1</td>
<td>2.08</td>
<td>1.39</td>
<td>1.50</td>
</tr>
<tr>
<td>DPT/Hib2</td>
<td>2.99</td>
<td>2.45</td>
<td>1.51</td>
</tr>
<tr>
<td>DPT/Hib3</td>
<td>3.92</td>
<td>3.49</td>
<td>1.94</td>
</tr>
<tr>
<td>Measles</td>
<td>1.23</td>
<td>1.35</td>
<td>0.96</td>
</tr>
<tr>
<td>Yellow fever</td>
<td>2.53</td>
<td>1.79</td>
<td>1.08</td>
</tr>
<tr>
<td>Fully vaccinated</td>
<td>3.94</td>
<td>3.09</td>
<td>1.89</td>
</tr>
<tr>
<td>Median def</td>
<td>2.08</td>
<td>1.40</td>
<td>1.45</td>
</tr>
</tbody>
</table>

(b) Estimates of roh:

<table>
<thead>
<tr>
<th>Vaccine</th>
<th>Segment sampling, weighted</th>
<th>Segment sampling, unweighted</th>
<th>EPI method</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCG</td>
<td>0.017</td>
<td>−0.010</td>
<td>0.088</td>
</tr>
<tr>
<td>Hep1</td>
<td>0.000</td>
<td>0.017</td>
<td>0.014</td>
</tr>
<tr>
<td>Hep2</td>
<td>0.285</td>
<td>0.049</td>
<td>0.052</td>
</tr>
<tr>
<td>Hep3</td>
<td>0.113</td>
<td>0.033</td>
<td>0.004</td>
</tr>
<tr>
<td>OPV0</td>
<td>0.006</td>
<td>0.006</td>
<td>0.020</td>
</tr>
<tr>
<td>OPV1</td>
<td>0.044</td>
<td>0.027</td>
<td>0.090</td>
</tr>
<tr>
<td>OPV2</td>
<td>0.021</td>
<td>0.026</td>
<td>0.067</td>
</tr>
<tr>
<td>OPV3</td>
<td>0.172</td>
<td>0.068</td>
<td>0.065</td>
</tr>
<tr>
<td>OPV4</td>
<td>0.033</td>
<td>0.035</td>
<td>0.086</td>
</tr>
<tr>
<td>DPT/Hib1</td>
<td>0.088</td>
<td>0.032</td>
<td>0.075</td>
</tr>
<tr>
<td>DPT/Hib2</td>
<td>0.163</td>
<td>0.119</td>
<td>0.077</td>
</tr>
<tr>
<td>DPT/Hib3</td>
<td>0.240</td>
<td>0.205</td>
<td>0.142</td>
</tr>
<tr>
<td>Measles</td>
<td>0.019</td>
<td>0.029</td>
<td>−0.006</td>
</tr>
<tr>
<td>Yellow fever</td>
<td>0.125</td>
<td>0.065</td>
<td>0.013</td>
</tr>
<tr>
<td>Fully vaccinated</td>
<td>0.242</td>
<td>0.172</td>
<td>0.134</td>
</tr>
<tr>
<td>Median roh</td>
<td>0.088</td>
<td>0.033</td>
<td>0.067</td>
</tr>
</tbody>
</table>

* The estimates of roh were computed as roh = (deff − 1)/(b − 1), where b = ∑g=1|g|, is a measure of the mean cluster size. Design effect estimates for the EPI method were computed without applying stratum weights.

** Expanded Program for Immunization.

b Bacillus Calmette-Guerin

c Hepatitis B.

d Oral polio vaccine.

e Diphtheria, pertussis, tetanus.

f Haemophilus influenzae type b.

Discussion

We conducted two surveys of vaccination coverage in Western Region of The Gambia within a short time of each other. The first survey used compact segments to select households, while the second survey used the EPI random walk method. There were other differences: the segmented survey used implicit geographical stratification while the EPI survey used three explicit geographical strata; and the sample size was 840 for the segmented survey versus 671 for the EPI survey. The effect of stratification on the estimated design effect and rate of homogeneity has been discussed earlier. The difference in sample size will have a small effect on the width of the CI, but will not affect the point estimates, or the estimates of design effect and rate of homogeneity. The difference in timing of the surveys may have had an effect on OPV coverage, as older children may have been vaccinated between the surveys during the National Immunization Days of the Polio eradication campaign.

The differences between the two methods in point estimates and confidence intervals were in most cases negligible. There was no clear pattern to differences in rate of homogeneity. To some extent these findings may be explained by the very high coverage for individual vaccines, but full vaccine coverage was not high and EPI sampling overestimated it by only 2%.

The EPI method falls short in two main aspects: the dependence on an out-of-date census for selection of clusters and the lack of objectivity of household sampling. Since the former is accounted for in segment sampling by the weighting, it may be evaluated by comparing the weighted and unweighted segment sampling estimates. In our survey, differences between these are almost non-existent. One would expect EPI sampling to perform badly in situations where there has been uneven population growth since the last census and that growth is highly correlated with the variable of interest. However, our calculations demonstrate that even in an extreme situation the bias is unlikely to be severe.

The lack of objectivity of household selection may be evaluated by comparing the unweighted segment sampling estimate with the EPI estimate. This is usually of the order of 1–2% in our study. However, our survey was conducted by an experienced team, and there may be more of a problem where staff are less well trained or supervised.

The EPI survey, and the interview phase of the segmented survey, each took a team of 16 interviewers about 5 weeks to complete. The mapping of households and preliminary enumeration for the segmented survey added a further 5 weeks...
to the fieldwork, but if segments were defined in terms of compounds, a simpler mapping exercise could be used. The theoretically ideal approach to surveys in the absence of a household sampling frame would be complete enumeration of all households in selected clusters, followed by random or systematic sampling of households, but such schemes demand carefully supervised field work and the weighting may become complex. Kish discusses in detail the advantages and disadvantages of compact segment designs versus complete enumeration. In standard (as opposed to compact) segment sampling, as used by the Demographic and Health Surveys, households in a selected segment are listed and a systematic sample taken. Compact segment sampling, in which all children in a segment are selected, avoids the accurate mapping and listing, but at the cost of a less precise estimate, because of increased homogeneity within the sample. Although we have shown that the effect of an out-of-date census is likely to be small, the EPI approach is still inferior to any of the other approaches mentioned, in that it is not possible to ensure objectivity of household selection, to deal appropriately with non-response or to estimate total numbers of those vaccinated (useful for planning). The choice to have the security of a probability design will depend on time and budget, but mapping need not add substantially to costs particularly if existing maps can be updated. However, it is encouraging to see that, at least when carried out by an experienced team, the EPI method can give accurate results.

Acknowledgements

The first survey was funded by the WHO and the MRC as part of a project to evaluate introduction of Hib vaccine into The Gambia. We are grateful to staff of Western Division and North Bank west Divisional Health teams, the Central Statistics Department, Banjul, Baboucar Daffeh, George Lahai, Uma Onwuchekwa, and Richard Adegbola, for help with fieldwork and survey management. In memory of Steve Bennett.

KEY MESSAGES

- The Expanded Program for Immunization (EPI) random walk method is widely used where a sampling frame is not available; it is quick and approximately self-weighting, but it is not a probability sample, and so cannot ensure objectivity of household selection, nor compensate for effects of population shift since the previous census.
- Selection of communities with probability proportional to an out-of-date measure of size will often mean that fast-growing urban areas, which may have the poorest access to health care, will be under-represented in the sample, and the overall estimate of coverage will be biased upwards. However, in practice this bias will usually be small, and with an experienced team the EPI method can give more accurate results.
- Compact segment sampling requires preliminary mapping but is a preferable method as it gives the security of a probability sample, can adjust for inaccuracies in the measure of size, and enables totals, such as the number of unvaccinated children, to be estimated, which is useful for planning.

References

3 Turner, AG, Magnani, RJ, Shuaib M. A not quite as quick but much cleaner alternative to the expanded programme on immunization (EPI) cluster survey design. Int J Epidemiol 1996; 25:198–203.