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ON ERROR IN THE ESTIMATE OF MALNUTRITION DUE TO BIAS AND RANDOM ERROR IN ANTHROPOMETRY AND AGE

by

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INTRODUCTION

Anthropometric indices are a valid and widely used technique for estimating malnutrition of children. The percentage of children below a certain cut-off point of an index is usually used as an estimate of malnutrition.

While this estimate of malnutrition is likely to be affected by measurement error in anthropometry, measurement error, large or small, is unavoidable in anthropometry. Some of the important anthropometric indices require age data of children. But accurate age is also not available in most of the developing countries. Although sources, level and pattern of error in anthropometry and age have been investigated in some studies (Bairagi 1981; Bairagi et al. 1982; Martorell et al. 1975), no systematic study on the effect of this error in the estimate of malnutrition is attempted yet. It is expected that a large error will have a large effect and a small error will have a small effect on the estimate. However, a quantification of the error in the estimate of malnutrition for different amount of error in the anthropometry and age is necessary to an investigator to make a decision about the amount of error that he may allow in his study. In this paper, error in the estimate of malnutrition measured by weight-for-age, height-for-age, arm circumference-for-age and weight-for-height due to different level of bias and random error in anthropomety and age is obtained.

METHODS AND RESULTS

Although the definitions of the anthropometric indices are well known and available in many places (Bairagi 1981; Waterlow 1977), the definition of the weight-for-age index is repeated here. This index of a child is defined as the ratio of the weight of the study child to the weight of a reference child. Notionally,

$$\text{Weight-for-age} = \theta^{w}_{a} = \frac{W_a}{W^{*}_{a}} \times 100,$$

where,

a = true age of the study child

W_a = true weight of the study child

W^*_a = weight of the reference child at age a

Usually, Harvard median weight (Jelliffe 1966), or National Centre for Health Statistics (NCHS) (Waterlow 1977) median weight is used as reference. The definitions of the other indices mentioned are also similar to that of the weight-for-age.

Let us assume that the true weight-for-age index of a child population be normally distributed with mean μ and variance σ^2. Let t be the cut-off point, and a child having an index value less or equal to t be considered as malnourished. The actual malnutrition is therefore —

$$P = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{t} e^{-\frac{1}{2\sigma^2}(O_a^w - \mu)^2} dO_a^w = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{\frac{t-\mu}{\sigma}} e^{-\frac{1}{2}y^2} dy$$

$$= \Phi\left(\frac{t-\mu}{\sigma}\right) \quad \text{where} \quad y = \frac{O_a^w - \mu}{\sigma} \qquad [1]$$

Let there be a bias in the weight measurement, which makes the mean as μ_1 instead of μ. Therefore the observed malnutrition in the population will be

$$P_1 = \Phi\left(\frac{t-\mu_1}{\sigma}\right)$$

The error in the estimate of malnutrition due to bias is

$$P_1 - P = \Phi\left(\frac{t-\mu_1}{\sigma}\right) - \Phi\left(\frac{t-\mu}{\sigma}\right) \qquad [2]$$

From (2) it appears that this error will be zero, if any of the following conditions is satisfied:

(i) $\mu = \mu_1$ i.e. bias is absent,

and (ii) $|t-\mu|$ is sufficiently large in comparison with σ, i.e. the cut off point is at the extreme end of the distribution of the index value. (P_1-P) will be maximum if the cut-off point $t=\mu$ (see Appendix A). For a given bias in weight, μ_1 may be calculated and error in the estimate of malnutrition, (P_1-P) may be obtained from (2) using normal probability integral (Fisher and Yates 1963).

It may be noted from equation (1) that to obtain error in the estimate σ should be known. Its value for the weight-for-age index for different populations is about 10 (Bairagi 1981; Waterlow 1976). Attained growth and rate in growth in

weight and height in Harvard reference and in arm circumference in Polish reference children are given in Table 1 (Jelliffe 1966,pp.220-226). The maximum error in the estimate of malnutrition due to a given bias in weight may be obtained easily from equation (2) taking information from Table 1. Here an example is given. Let the children be exactly 3 years old and their true mean weight be 12 kg. Let the bias be -0.6 kg.

$$\mu = \frac{12}{14.5} \times 100 = 82.76$$

$$\mu_1 = \frac{12 - 0.6}{14.5} \times 100 = 78.62$$

If the cutoff point is at μ,

$$P_1 - P = \Phi\left(\frac{82.76 - 78.62}{10}\right) - \Phi(0) = 0.66 - 0.50 = 0.16$$

That is, $P_1 - P = 16\%$.

Although means of the anthropometric indices are very much different between different child populations, standard deviations of the indices across the population are about the same and are found to be approximately 10, 6, 10 and 10 for weight-for-age, height-for-age, arm circumference-for-age and weight-for-age respectively. The results of Table 2 are obtained using these standard deviations and following the above example.

In Table 2, only the error in the estimate of malnutrition due to bias in anthropometry and age is given. This estimate may also be affected by random error. Let ϵ be the random measurement error in the weight-for-age index which would be independently and normally distributed with mean 0 and variance σ_ϵ^2. Therefore, variance $(\sigma_a^w + \epsilon) = \sigma^2 + \sigma_\epsilon^2$

Let t again be the cut-off point. The actual malnutrition is

$$P = \Phi\left(\frac{t - \mu}{\sigma}\right)$$

and the estimated proportion of malnutrition is

$$P_2 = \Phi\left(\frac{t - \mu}{\sqrt{\sigma^2 + \sigma_\epsilon^2}}\right)$$

Error due to random measurement error is

$$P_2 - P = \Phi\left(\frac{t - \mu}{\sqrt{\sigma^2 + \sigma_\epsilon^2}}\right) - \Phi\left(\frac{t - \mu}{\sigma}\right) \qquad [3]$$

From (3) it appears that error in the estimate will be zero, if any of the following conditions is satisfied:

(i) $\sigma_\epsilon = 0$, i.e., no random error is present,

(ii) $t = \mu$, i.e., cut-off point is at the mean,

(iii) $|t - \mu|$ is sufficiently large in comparison with σ and σ_ϵ i.e. if the cut-off point is set at the extreme ends of the distribution of the index.

(P_2-P) will be maximum for a given value of σ_ϵ if $|t-\mu| = \sigma$ (see Appendix B). The error at that point will be -

$$P_2 - P = \Phi\left(\frac{-1}{\sqrt{1+\frac{\sigma_\epsilon}{\sigma}}}\right) - \Phi(-1) = \Phi\left(\frac{-1}{\sqrt{1+\frac{\sigma_\epsilon}{\sigma}}}\right) - 0.16 \qquad [4]$$

Measurement error variance of the indices for measurement random error in anthropometry and age is obtained elsewhere (Bairagi 1981, pp 46-50). This variance for weight-for-age is -

$$\sigma_\epsilon^2 = \frac{1}{W_a^{*2}}\left[\sigma_{wt}^2 + (\theta_a^w)^2 (\beta_a^w)^2 \sigma_{a\epsilon}^2\right] \times 100^2 \qquad [5]$$

W_a^* and θ_a^w have been defined earlier, $\sigma_{w\epsilon}^2$ is the measurement error variance in weight, β_a^w is the monthly rate of growth in weight at age a, and $\sigma_{a\epsilon}^2$ is the reported error variance in age. The error in the estimate of malnutrition for a given error variance in weight measurement may be obtained as follows:

Let the children be 3 years old, and measurement error variance in weight be 0.4 kg^2.

$$\sigma_\epsilon^2 = \frac{1}{14.5^2}\left[0.4 + 0\right] \times 100^2 = 19.02$$

From (4), $P_2 - P = \Phi\left(\frac{-1}{1 + 19.02/100}\right) - 0.16 = 0.20 - 0.16 = 0.04$

$P_2 - P = 4\ \%$

The results of Table 3, in which the error in the estimate of malnutrition measured by different anthropometric indices due to different level of measurement random error given, are obtained following the above example. It may be noted that a value of the index, say θ_a^w, is required to obtain the

measurement error variance of the index for a given error variance in age. Average index value is likely to differ from population to population. A population with higher values of an anthropometric index is more susceptible to random age error. For the calculation of the results of Table 3 the index value taken for the weight-for-age is 75%, for the height-for-age is 90%, for the arm circumference-for-age is 80% and for the weight-for-age is 80%. The average index values of the developing countries are close to these figures.

DISCUSSION

The error in the estimate of malnutrition due to bias and random error in anthropometry and age presented in Tables 2 and 3 is obtained assuming that each of the indices is normally distributed. This assumption is reasonable, and some deviations from normality are not likely to affect the results much.

Here the error in the estimate is calculated only for 3 year old children. For a given amount of bias or random error, the error in the estimate will be more for younger children than for older children. However, the results of Table 2 and 3 are reasonably applicable for the children whose average age is close to 3 years.

Although the error in the estimate due to bias is maximum if the cut off point is at the mean, this error will not be much less if the cut-off point remains within one unit of standard deviation from the mean. It may be stated in a different way that the results of Table 2 are reasonably applicable if the cut-off point is set at a point so that the actual malnutrition in the population is between 16 and 84 percent.

How much error in the estimate of malnutrition is tolerable is difficult to answer. It depends on the purposes of investigations. Probably a difference of 5% points between the populations or in a population over time is large enough to draw the attention of the investigator. Such a difference also appears as statistically significant ($P < 0.05$) with a sample of size of about 800 children. But such a difference is possible artifically if only a bias of 0.05 cm in height or

0.02 kg in weight, or 0.02 cm in arm circumference at 1 month in age is present.

In a well conducted study the biases were 0.47 kg in weight, -0.624 cm in height and -1.659 cm in arm circumference where the data were collected in two institutes by well-trained workers using the same set of equipments (Kemper and Pieters 1974). The bias in age data was found to be 2.5 months in a recent study in Bangladesh (Bairagi et al 1982). These results provide evidence that accuracy in anthropometry and age deserve serious attention.

Martorell et al (1977) estimated random measurement error variance as 0.04 kg^2 in weight, 0.12 cm^2 in height and 0.05 cm^2 in arm circumference. In another study (Bairagi 1981) these variances were estimated as 0.04 kg^2, 0.09 cm^2 and 0.03 cm^2 respectively. Of course in the second study measurement error variance was estimated as 0.80 kg^2 when the weights were taken on one kind of beam balance instead of Salter scale. Error variance in age of a group of children aged between 22 and 59 months was 60 months in a study in rural Bangladesh (Bairagi et al 1982). These estimates and the results of Table 3 demonstrated that random error is not a big problem in estimating malnutrition.

Bias and random error described here are non-sampling error. Not the increase in sample size but the increase in accuracy in measurement is the solution to reduce their effects. This accuracy may be obtained considerably by recruiting good workers, giving them good training, using good instruments and standardizing the techniques. An estimate of malnutrition can't be considered as error free without knowing that anthropometric and age data are free from error.

TABLE 1

ANTHROPOMETRIC STANDARDS (ATTAINMENT AND GROWTH) AT DIFFERENT AGES*

Age (Months)	Standard Weight (kg.)	Standard Wt. Gain (kg/mth)	Standard Height (cm)	Standard Ht. Gain (cm/mth)	Standard Arm Circ. (cm)	Standard Cir. Gain (cm/mth)
6	7.4	0.50	65.8	1.8	14.4	0.30
12	9.9	0.30	74.7	1.3	15.8	0.03
24	12.4	0.20	87.1	0.9	16.1	0.02
36	14.5	0.17	96.0	0.7	16.1	0.02
48	16.5	0.16	103.3	0.6	16.9	0.02

*Harvard standard was used for weight and height and Polish standard was used for arm circumference.

TABLE 2

Error in the estimate of malnutrition due to bias in anthropometry and age for different indices for children aged 3 years

(Error ± percent points)

Bias in height (cm)	Weight for age	Height for age	Arm Circumference for age	Weight for Height
0.5	-	4	-	4
1.0	-	7	-	7
1.5	-	10	-	10
2.0	-	14	-	14
2.5	-	17	-	17
Bias in weight (kg)				
0.2	5	-	-	5
0.4	11	-	-	11
0.6	16	-	-	16
0.8	21	-	-	21
1.0	25	-	-	25
Bias in arm circumference (cm)				
0.2	-	-	5	-
0.4	-	-	11	-
0.6	-	-	16	-
0.8	-	-	21	-
1.0	-	-	25	-
Bias in age (month)				
1.0	5	5	0	-
2.0	9	9	1	-
3.0	13	14	2	-
4.0	17	18	3	-
5.0	21	22	4	-

TABLE 3

Error in the estimate of malnutrition due to random error in anthropometry and age for different indices for children aged 3 years

Measurement error variance	(Error ± percent points) Weight for age	Height for age	Arm Circumference for age	Weight for Height
height (cm^2)				
1.0	-	0	-	0
2.0	-	1	-	0
3.0	-	1	-	0
4.0	-	1	-	1
5.0	-	2	-	1
weight (kg^2)				
0.2	1	-	-	1
0.4	2	-	-	2
0.6	3	-	-	3
0.8	4	-	-	4
1.0	5	-	-	5
arm cir. (cm^2)				
0.2	-	-	1	-
0.4	-	-	2	-
0.6	-	-	3	-
0.8	-	-	4	-
1.0	-	-	5	-
age ($month^2$)				
20.0	2	3	0	-
40.0	3	5	0	-
60.0	4	6	0	-
80.0	6	8	0	-
100.0	7	9	0	-

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APPENDIX A

Estimation of the cut-off point at which error due to bias in the estimate of malnutrition is maximum

$$P_1 - P = \Phi\left(\frac{t-\mu_1}{\sigma}\right) - \Phi\left(\frac{t-\mu}{\sigma}\right)$$

$$\frac{\partial(P_1-P)}{\partial t} = \frac{1}{\sigma\sqrt{2\pi}}\left[\exp\left\{-(t-\mu_1)^2/2\sigma^2\right\}\right] - \frac{1}{\sigma\sqrt{2\pi}}\left[\exp\left\{-(t-\mu)^2/2\sigma^2\right\}\right]$$

Setting $\frac{\partial(P_1-P)}{\partial t} = 0$, and solving for t,

$$(t-\mu_1)^2 = (t-\mu)^2$$

$$-2t\mu_1 + \mu_1^2 = -2t\mu + \mu_2^2$$

$$2t(\mu-\mu_1) = (\mu+\mu_1)(\mu-\mu_1)$$

$$t = \frac{\mu+\mu_1}{2}$$

In practical situations, μ and μ_1, will not be very different due to bias in any of the anthropometry and age. Therefore,

$$t \simeq \mu$$

APPENDIX B

Estimation of the cut-off point at which error due to random error in anthropometry and age in the estimate of malnutrition is maximum.

$$P_2 - P = \Phi\left(\frac{t-\mu}{\sqrt{\sigma^2+\sigma_\epsilon^2}}\right) - \Phi\left(\frac{t-\mu}{\sigma}\right)$$

$$\frac{\partial(P_2-P)}{\partial t} = \frac{1}{\sqrt{2\pi(\sigma^2+\sigma_\epsilon^2)}}\left[\exp\left\{-(t-\mu)^2/2(\sigma^2+\sigma_\epsilon^2)\right\}\right]$$

$$- \frac{1}{\sigma\sqrt{2\pi}}\left[\exp\left\{-(t-\mu)^2/2\sigma^2\right\}\right]$$

Setting $\frac{\partial(P_2-P)}{\partial t} = 0$, and solving for $(t-\mu)$,

$$|t-\mu| = \left[\ln\frac{\sigma^2+\sigma_\epsilon^2}{\sigma^2} \Big/ \left\{\frac{1}{\sigma^2} - \frac{1}{\sigma^2+\sigma_\epsilon^2}\right\}\right]^{1/2}$$

Since $\ln\frac{\sigma^2+\sigma_\epsilon^2}{\sigma^2} = \ln\left(1+\frac{\sigma_\epsilon^2}{\sigma^2}\right) \cong \frac{\sigma_\epsilon^2}{\sigma^2}$ when

$\frac{\sigma_\epsilon^2}{\sigma^2}$ is a small quantity;

$$|t-\mu| \cong \sigma$$

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