COMPARING THE RESPONSIVENESS OF DIARRHEAL RATES WITH CHILD GROWTH IN JUDGING THE HEALTH IMPACT OF IMPROVED WATER AND SANITATION

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BU-848-M August, 1984

Abstract

Reports of a lack of a reduction in diarrheal rates following water and sanitation improvements could be due, in part, to the fact that the measurements of these rates are unresponsive to true changes in diarrheal incidence or prevalence. This paper examines the potential for using measurements of child growth for measurements of health benefits of improved water and sanitation.

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KEY WORDS: Anthropometry; Diarrhea; Epidemiological methods; Sanitation; Statistics; Water supply.

INTRODUCTION

It is generally believed that improvements in water supply and excreta disposal facilities in developing areas will improve people's health, primarily through a reduction in the incidence of diarrhea. This is expected to be achieved by reducing the ingestion of pathogens. These improvements are usually directed for children under five years of age because of their high incidence of diarrhea.

Most efforts to substantiate these improvements have attempted to show differences in diarrheal incidence or prevalence between two or more groups of children living under differing levels of water and sanitation conditions. Many such attempts have failed, suggesting that diarrheal indicators may not be sensitive enough to measure expected changes. Although methodological problems have been systematically identified from previously published reports (1, 2), the choice of indicators with which to show health improvements (or disease reductions) presents a previously unrecognized problem. Some studies have attempted to show differences in infection rates between two or more groups, but infection may or may not result in diarrhea, and the logistics and cost of measuring specific enteric pathogens make this approach difficult in all but a few studies. Mortality rates have also been measured and compared, but these studies require much larger sample sizes than morbidity studies to show significant differences between two or more groups.

Even fewer studies have used nutritional anthropometric indicators to measure improved health (or reduced disease). Child nutritional anthropometric indicators are useful to include in health impact evaluations of water and sanitation projects for four reasons. First, a biological pathway links infection and diarrhea to stunted growth (3). Second, nutritional anthropometric indicators may be as or more measurably responsive than diarrheal rates to reductions in diarrhea. Third, water and sanitation projects may affect anthropometry through other mechanisms than reduced ingestion of diarrheal pathogens (Figure 1), making anthropometry a better proxy of overall health improvements due to improved water and sanitation. Fourth, anthropometric measurements are well-defined, quickly and cheaply performed by previously untrained enumerators, and do not rely on recall of frequent home visits.

DETERMINANTS OF NUTRITIONAL ANTHROPOMETRIC INDICATORS

There are two major determinants of child growth; heredity and environmental factors. Heredity, as defined by race or ethnicity, plays a minor role during the first years of life in determining differences in height and weight across different populations when compared to the role played by environmental factors (4, 5). Well-to-do preschoolers from different ethnic groups throughout the world have normal growth patterns and attain heights and weights similar to well-to-do preschoolers from industrialized countries. Less well-to-do children, however, can be found to be significantly shorter and lighter than their ethnic counterparts. Variability in growth across different populations around the world is thus better explained by environmental factors than by heredity.

Many environmental factors affect child growth, but essentially the process of nutrition, or the ingestion, absorption, and utilization of available nutrients is the key mediating determinant of any environmental factor. If nutrition changes so that the balance between intake and expenditure of energy and protein is deficient, a net loss of body mass will result. Muscle tissue and fat stores will be depleted and a deceleration or cessation of growth will occur. Nutritional anthropometry is sensitive enough to measure these changes in nutriture (6). Water and sanitation projects affect growth mostly through reduced exposure to pathogens which is related to the ability of the body to ingest, absorb and utilize available nutrients. Because nutrient availability may also be related to water and sanitation projects (Figure 1), through improvements in home gardening, child care, and food preparation, the use of nutritional anthropometry can be affected by more mechanisms than just reduced infection.

Enteric infection and disease may result in anorexia, malabsorption and catabolism of nutrients. During diarrhea it has been reported that nutrient intake may be reduced by 20-50% (7, 8, 9). These results hold for within and between child comparisons (8). Although some of the reduction may be due to withholding of food, efforts to improve food intake during diarrhea failed (7).

A review of the documented evidence of malabsorption during diarrhea (10) reported that bacterial, viral and protozoal infections led to malabsorption of carbohydrate, protein, fat, and micronutrients. Malabsorption of protein, fat, and calories occurred when gut epithelial cells were impaired during rotavirus infection and when they were left intact during cholera (11). Malabsorption continued during convalescence. It is also well known that important losses of water and electrolytes occur during diarrhea.

Catabolic consequences of infection and diarrhea lead to a breakdown of muscle tissue and a loss of fat stores. Fever, often accompanied by bouts of diarrhea, has a wide array of metabolic consequences (12). Some of the more salient features include the following: increased metabolic rate; dermal losses of electrolytes; and evidence of a loss of body protein. Such loss of body protein was also reported to occur in the absence of fever. Thus infection, with or without fever, depletes body nutrients.

All of these processes, singularly and in unison, affect nutrition, which in turn, affects linear growth and weight gain of children.

DIARRHEA AND NUTRITIONAL ANTHROPOMETRY

All studies of the issue show an association of growth stunting with diarrhea. It is important that this association is, above all, due to diarrhea stunting growth rather than because malnutrition causes diarrhea, if anthropometry is to be used to measure the impact of water and sanitation projects on diarrhea.

While some studies have reported an association between diarrhea and nutritional anthropometry without specifying the direction of this relationship (13, 14, 15), other studies have consistently reported that diarrhea contributes to poor growth, as measured by height and weight (16, 17, 18, 19, 20, 21, 22).

The magnitude of stunting due to diarrhea is considerable. In Guatemalan children 15 months - 7 years of age, those with less diarrhea grew 6% more in length and 11% more in weight (17) than the high diarrhea group -- and this was equally true of comparisons within a same child between periods of high and low diarrhea. Rowland *et al.* (19) reported that up to 50% of growth faltering was due to diarrhea. A study from Bangladesh reported that certain enteric pathogens affected growth more than others (20). Diarrhea caused by *Shigella* and enterotoxigenic *E. Coli* affected growth more than other diarrheas. *Shigella* and enterotoxigenic *E. Coli* had different effects on growth in that the former tended to stunt linear growth more than the latter, while the reverse was true of impaired weight gain.

If body size affected the incidence of diarrhea, then the usefulness of anthropometric indicators for evaluating water and sanitation projects would be diminished. Published reports are contradictory as four studies have reported no relationship between body size and subsequent diarrhea rates (23, 24, 25, 26), while four studies reported positive associations (22, 27) Prevalence may be affected by a child's nutritional status since the duration of diarrheal episodes has been reported to be affected by body size (22, 23, 26, 27, 28, 29). However, this relationship may only last for a short period of a few months (29) and be inconsequential in health impact evaluations. Those studies finding an association between poor growth and subsequent diarrhea did not attempt to control for previous diarrhea. Thus the inference that malnutrition caused diarrhea may be spurious. Nutritionally deprived children may have impaired growth because of prior diarrhea. If the conditions which lead to past diarrhea continue to persist, then a higher prevalence of diarrhea during these studies would have occurred. Thus the association between stunted growth and subsequent diarrhea may have been mediated by the conditions which fostered both past and present diarrhea.

In conclusion, those studies which have convincingly identified the direction of this relationship show that the causal association is overwhelmingly that diarrhea causes stunting (16, 17, 18, 19, 20, 21, 22). Less than half (23, 24, 25, 26) of the studies which looked for malnutrition as reflected in growth affecting subsequent diarrhea found any association and this could have been due to confounding factors. At any rate it was of a much smaller magnitude than the association in the opposite direction. Thus the major association of growth with diarrhea is caused by diarrhea stunting growth. Growth can therefore be considered as a potential proxy for diarrheal rates.

There is evidence that the other pathways in Figure 1 also lead to improved growth among young children, although these mechanisms have been relatively unexplored in relation to water supplies. Improved water supplies have reduced the time spent collecting water (30, 31, 32). If this time is converted into better child care by mothers, then growth may be improved (30) as measured by anthropometry In areas of severe water deficiency more water may allow for food to be prepared more often (31). This would increase nutrient availability and reduce exposure to pathogens since prepared food left at room temperatures permits bacterial proliferation (33, 34, 35, 36). If energy expenditure of mothers is reduced by bringing water nearer to homes (37), breastfeeding may possibly be fostered and contribute to a larger share of a child's diet. Breastfeeding confers immunity to children and reduces their exposure to pathogens, thus reducing diarrheal rates (38). This would also increase the caloric content of a child's diet since weaning foods often lack caloric density (39). If more water allows for increased food production from home gardens and directly or indirectly (through increased income), this may improve nutrition and also improve growth (40).

REVIEW OF STUDIES REPORTING AN ASSOCIATION BETWEEN WATER AND SANITATION AND NUTRITIONAL ANTHROPOMETRY

Eight studies have reported differences in height and weight between two or more comparison groups differing in water and sanitation conditions (28, 30, 41, 42, 43, 44, 45, 46). Three anthropometric indicators of nutritional status were used alone or together in these studies. Weight-for-height (W/H) values are age independent and measure wasting, or recent nutritional insults. This indicator is subject to recent bouts of diarrhea, when it may fall below a normal or previously low level. Height, as indicated by height-for-age (H/A), measures linear growth, does not decline over time, and is a good measure of chronic or past undernutrition. As such it would measure the effects of repeated bouts of diarrhea or past deficits in nutrition. Weight-for-age (W/A), the most commonly reported measure of nutritional anthropometry, is less descriptive than the above two indicators because it does not distinguish between chronic (H/A) and acute (W/H) malnutrition. However, for just these reasons it may be a good indicator.

Most studies reported benefits for attained weight, height, or both, but there were inconsistencies within and across studies. Attained values measure growth from conception to the time of measurement, but cannot measure growth over the most crucial time period, weaning. One study (43) reported incremental weight gain over three-month intervals, up to 24 months of age, covering the weaning period. No differences were reported between the better-off and worse-off groups except for the period 3-6 months.

In summary, the results are inconclusive but suggest that anthropometry can measure differences between better-off and worse-off groups. Some of these differences, however, could have been due to confounding factors. Although measures of weight and height are likely to improve after water and sanitation intervention, it must be determined if measuring these indicators is an improvement relative to measuring diarrheal indicators. A more direct method of comparing these two indicators is required.

RESPONSIVENESS OF ANTHROPOMETRIC INDICATORS AND DIARRHEA

Priority should go to the indicator which best identifies the important consequences of an intervention. Such an indicator may be said to be responsive to the intervention. In the case of water and sanitation interventions to reduce exposure to enteric pathogens, the consequence of interest is child health. In the past, diarrhea measurements were chosen because they were thought to be that aspect of health which would be most affected. Child growth is more distantly related to enteric pathogens than is diarrhea. Therefore, child growth might be more likely to be observed by other influences.

Of course if extraneous factors influence one comparison group more than another, the difference found between the comparison groups will not be due to differences in water and sanitation. The two comparison groups are confounded by this bias. The more distant a variable is from the presumed mechanism by which an intervention works, the more opportunities there are for such confounding. However, it is important to realize that the probability of confounding does not necessarily correspond to the differences in number of opportunities. Thus, measuring the variable that is closer to the mechanism of action does not necessarily reduce the probability of confounding. Furthermore, there are well recognized techniques for eliminating and controlling (47) confounding so that this is often not a pertinent argument for using diarrhea instead of child growth as a measurement of impact.

Knowing that more factors influence child growth than influence diarrheal rates resulted in a second inference: that identifying the improvements in child growth due to diminished diarrhea subsequent to an intervention must be more difficult than identifying the effect of the intervention on diarrhea itself. This section deals with that issue. The question is, "Which is more responsive to a water and sanitation intervention, measurements of diarrhea or measurements of child growth?"

Responsiveness may be defined as the difference in the estimated mean value of an indicator (between the control and treatment groups or pre- and post-intervention values), divided by the pooled standard deviation of the two comparison groups (48). This ratio and the sample size determine the statistical power of the test; that is, the ability of the test to detect a difference in disease or health between different water and sanitation groups. This ratio extends the concept of Yates' (49) "sensitivity" ratio which compares different statistical tests on a same indicator, to a way of comparing indicators on a same statistical test. We use the term "responsiveness" to describe this ratio because "sensitivity" has a well accepted but quite different meaning in epidemiology (50). The responsiveness of an indicator and the sensitivity of a diagnostic test using that indicator are related, but in an ill-defined manner.

The number of negative findings using diarrhea data in the literature suggest that diarrhea may not be a responsive indicator. For nutritional anthropometric indicators to be useful in evaluation of water and sanitation programs, their responsiveness must be shown to be at least as responsive as diarrhea measurements. Using data from Martorell *et al.* (17), a comparison of the ratio of the responsiveness for each indicator referred to as relative responsiveness, can be calculated by the formula

$$\text{relative responsiveness} = \frac{\text{responsiveness of anthropometry}}{\text{responsiveness of diarrhea}}$$

$$= \frac{\dfrac{|\bar{Y}_B - \bar{Y}_W|}{S_A}}{\dfrac{|\bar{X}_B - \bar{X}_W|}{S_D}}$$

where

$\bar{X}_B$ = average diarrhea measurement for the group with better water and sanitation

$\bar{X}_W$ = average diarrhea measurement for the group with worse water and sanitation

$\bar{Y}_B$ = average anthropometric measurement for the group with better water and sanitation

$\bar{Y}_W$ = average anthropometric measurement for the group with worse water and sanitation

S_D = pooled standard deviation for the diarrhea measurements

S_A = pooled standard deviation for the anthropometric measurements .

A relative responsiveness of one indicates the two indicators are equally responsive, values less than one indicate diarrhea is more responsive and values greater than one indicate anthropometry is more responsive.

The study by Martorell *et al.* (17) is not based on a water or sanitation project and therefore does not give estimates of the mean differences between the better-off and the worse-off groups. However, it does give estimates of within-group variability for diarrhea as recalled over the previous 14 days and anthropometric measurements, so a relationship between the two can be calculated independent of knowing how much diarrhea or growth would be affected after improving water or sanitation conditions. This is predicated on the assumption that there is a linear relationship between diarrhea and anthropometry, that the diarrhea and anthropometry was measured perfectly, and that the only effect due to anthropometry is through the diarrhea pathway (Figure 1). These assumptions are unreasonable and load the comparison in favor of diarrhea in the following estimates of relative responsiveness.

The estimated difference in anthropometric measurements between the better-off or worse-off group would be the absolute value of the slope coefficient |b|, in the relationship of diarrhea and anthropometry times the estimated difference for diarrhea (see Figure 2). The formula for relative responsiveness then simplifies to

$$\text{relative responsiveness} = \frac{\dfrac{|\bar{Y}_B - \bar{Y}_A}{S_A}}{\dfrac{|\bar{X}_B - \bar{X}_A|}{S_D}} = \frac{|b|\,S_D}{S_A} \quad .$$

Using the data from Martorell *et al.* (3) responsiveness for height and weight can be calculated. Using the overall slope from 0-7 years of age, anthropometry is about one tenth as responsive as diarrhea. This ratio is, however, highest (.11-.16) during the most critical time periods, 6-24 months (Table 1). This is the weaning period when diarrhea rates are also highest and when most of the growth faltering occurs. Thus this is the time when both diarrhea and growth should be most responsive. During this age diarrhea is only about 6-9 times as responsive as either height or weight (Table 1).

When the simplifying assumptions made in the above calculations are challenged and taken into account, the relative responsiveness increases even more in favor of anthropometry.

First, there may not be a linear relationship between diarrhea and growth. Evidence exists which suggests that as diarrhea increases growth faltering becomes more severe. Of the two studies which reported slopes of growth by diarrhea (3, 19), the one in which children suffered more diarrhea (19) also had the largest negative slope coefficient. In Martorell *et al.* (3) slopes corresponding to 6-month intervals of life were also reported. The intervals corresponding to the most diarrhea also had the largest negative value slopes. This relationship is depicted in Figure 3.

When diarrhea rates are high in a given population and there is a reduction in diarrhea following a water or sanitation intervention, slopes based on a nonlinear relationship between growth and diarrhea will be larger than slopes based on a linear relationship. Thus, relative responsiveness will increase making nutritional anthropometry more responsive relative to diarrhea indicators. Although nonlinear slopes have not been reported, age-specific regression coefficients from Martorell (3) approximate these nonlinear slopes.

The corollary to the above argument is that given a population with little diarrhea, the linear and nonlinear slopes may not be much different. The use of nutritional anthropometry in this case would not be advantageous. However, since the diarrhea rates are also low and it would be unlikely in this setting that water and sanitation improvements would lead to a measurable change in diarrhea (51), one would not want to measure a health change in this situation.

A second assumption made in the above calculations is that diarrhea is accurately measured. In practice, however, diarrhea is not accurately measured. There is good evidence (28, 52) to suggest that the apparent difference between the better- and worse-off groups will be smaller than the true difference because of underreporting. Underreporting of 30% can occur when using a seven-day recall and can be as high as 43% or more in a two-week recall period and this will cause a corresponding increase in relative responsiveness. Correcting for underreporting of diarrhea increases the relative responsiveness of anthropometry to diarrhea by 1.75 (=1/.57). A third assumption is that the anthropometry is without error. The standardization methods used to collect the data reported by Martorell guaranteed negligable systematic over- or under-measurements. However, a large part of the variance of incremental anthropometry (41% for weight and 15% for height) was due to a combination of measurement error and day-to-day variability in the measurements (6). This unreliability attenuated the slope, |b|, relative to the true slope by 23% for weight and by 18% for height.

Correcting for the underreporting of diarrhea and for the unreliability of anthropometry of the data used here raises the relative responsiveness by 2.284 for weight gain and by 1.905 for height gain relative to diarrhea. This adjustment combined with the age specific slopes, |b|, are presented in Table 2.

Finally, these relative responsivenesses around .3 for the critical weaning period, 6-30 months, diarrheal measurements were taken every 14 days, while anthropometric measurements were only taken every six months. Thus, roughly 12 times as many diarrhea measurements were needed. If we could instead measure 12 times as many children (once every six months rather than every 14 days) at approximately the same cost, then the power of a test based on anthropometric measurements is close to that of a test based on diarrhea measurements or better (Table 3). Measuring less frequently than six months would save even more and would be quite feasible (see Table 4). Figure 2 illustrates the various scenarios for 18-24 month old children.

All of the above calculations were based on the assumption that water and sanitation improvements only affect anthropometric measurements through reduced diarrhea. If pathways other than through diarrhea are appreciable contributors to the effect seen in the anthropometric indicators, then the relative responsiveness is increased by a like amount. For example, if only 70% of the effect due to anthropometry is through the diarrhea pathway, then the relative responsiveness would be increased by 43% (1/0.7) of its previous value.

Lastly, water and sanitation projects affect certain pathogens more than others (51). For example, such projects may reduce *Shigella* by about 50, more than any other pathogen investigated. Considering that growth is affected more by *Shigella* than other pathogens (20) and that *Shigella* contributes about 5-15% of all diarrhea, relative responsiveness can be reduced even more.

In summary, with perfect measurement at frequent intervals, diarrhea <u>may</u> be as much as ten times as responsive as anthropometric measurements. However, under realistic conditions, with underreporting of diarrhea and other operative pathways in Figure 1, tests based on anthropometric measurements are likely to be as powerful or more powerful than tests based on diarrhea for the same cost. We therefore urge those evaluating the health impact of water and sanitation projects to include anthropometry so as to empirically test the above conclusions.

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Table 1. Relative responsiveness[1] of height and weight gain to diarrhea duration (assuming a linear relationship[2] between growth and diarrhea)

	Relative Responsiveness	
Age in months	Height	Weight
0.5-6	.074	.106
6-12	.121	.154
12-18	.114	.156
18-24	.113	.110
24-30	.095	.101
30-36	.108	.103
36-42	.047	.045
42-48	.081	.057
48-60	.084	.067
60-72	.098	.072
72-84	.031	.026

[1] See text page 10

[2] Calculated assuming a slope of -.083 cm/day for length and a slope of -4.4 g/day for weight.

Table 2. Relative responsiveness[1] of height and weight gain to diarrhea (assuming 43% underreporting of diarrhea and adjusting for a nonlin ar relationship[2] between growth and diarrhea and unreliability of the anthropometry[3])

	Relative Responsiveness	
Age in months	Height	Weight
0.5-6	.024	.127
6-12	.075	.352
12-18	.203	.342
18-24	.309	.428
24-30	.135	.058
30-36	.079	.086
36-42	.008	.191
42-48	.069	.365
48-60	.421	.242
60-72	.432	.330
72-84	.366	.184

[1] See text page 10

[2] Calculated using age-specific slopes

[3] See text page 14

Table 3. Relative responsiveness[1] of height and weight gain to diarrhea (assuming 43% underreporting of diarrhea, adjusting for a nonlinear relationship[2] between growth and diarrhea and unreliability of the anthropometry[3] and assuming growth measurements taken only every 6 months)

	Relative Responsiveness	
Age in months	Height	Weight
0.5-6	.082	.439
6-12	.260	1.219
12-18	.705	1.184
18-24	1.071	1.484
24-30	.471	.200
30-36	.275	.296
36-42	.026	.662
42-48	.238	1.266
48-60	1.457	.838
60-72	1.497	1.145
72-84	1.267	.639

[1] See text page 10

[2] Calculated using age-specific slopes

[3] See text page 14

Table 4. Relative responsiveness[1] of height and weight gain to diarrhea (assuming 43% underreporting of diarrhea, adjusting for a nonlinear relationship[2] between growth and diarrhea and unreliability of the anthropometry[3] and assuming growth measurements taken only every 12 months)

	Relative Responsiveness	
Age in months	Height	Weight
0.5-6	.071	.348
6-12	.698	1.699
12-18	1.263	1.968
18-24	1.063	.860
24-30	.529	.363
30-36	.122	.990
36-42	.108	1.375
42-48	1.192	1.563
48-60	2.061	1.185
60-72	2.117	1.619
72-84	1.791	.903

[1] See text page 10

[2] Calculated using age-specific slopes

[3] See text page 14

FIGURE 1 :

Causative mechanisms relating improvements in water and sanitation to child growth

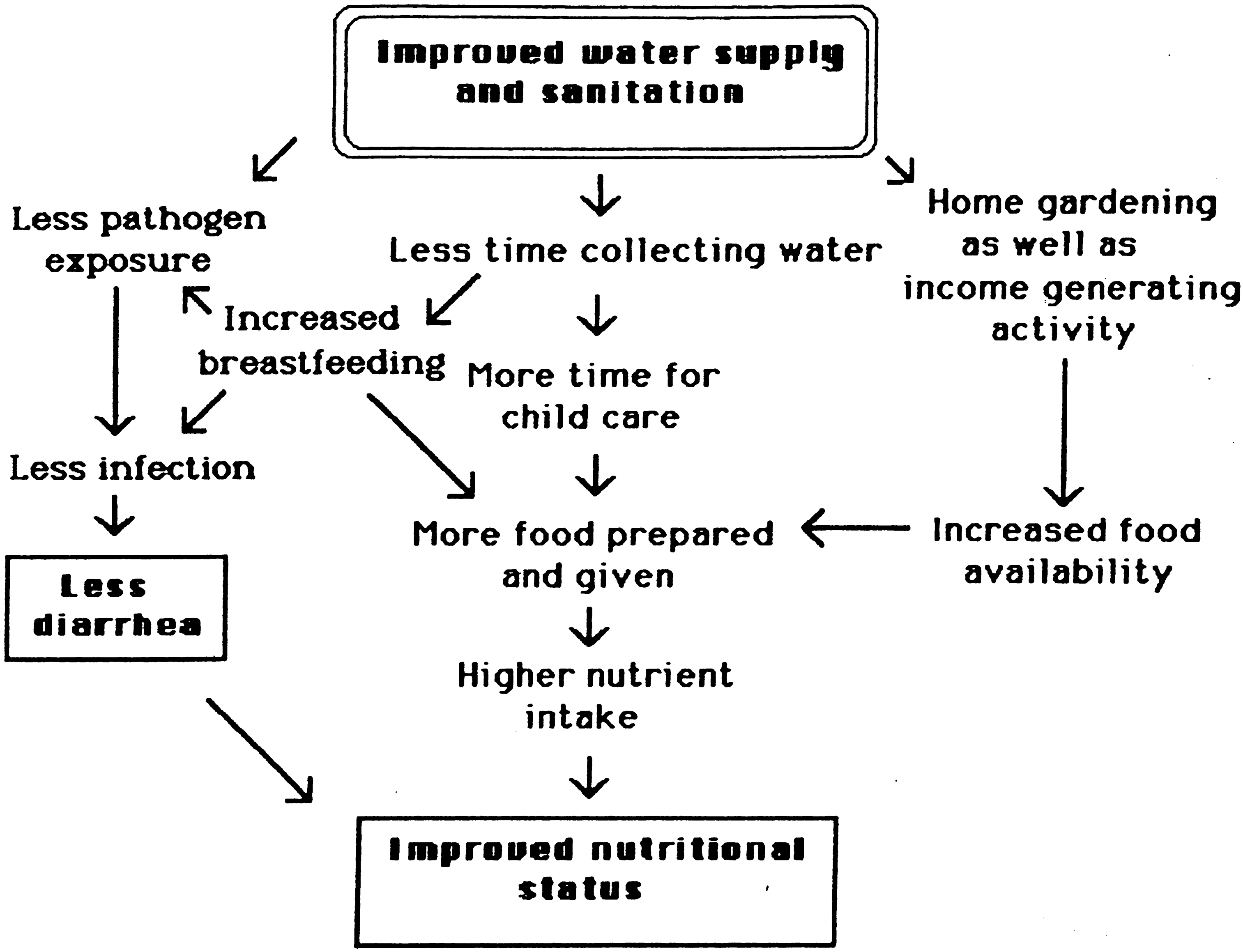

FIGURE 2: Relationships between growth increments and days ill with diarrhea and estimated differences between better- and worse-off groups

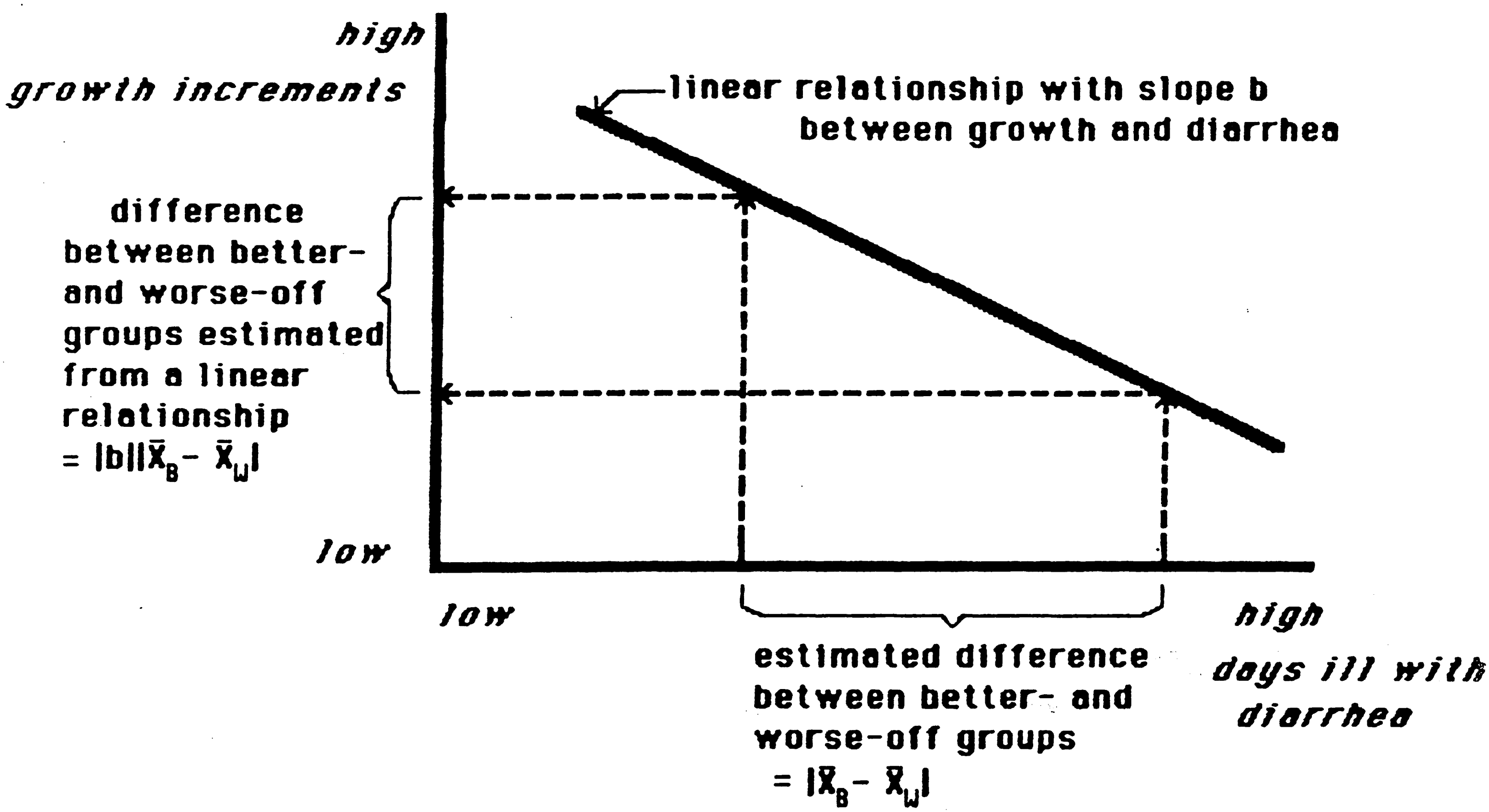

FIGURE 3: **Linear and nonlinear relationships between growth and days ill with diarrhea and estimated differences between better- and worse-off groups**

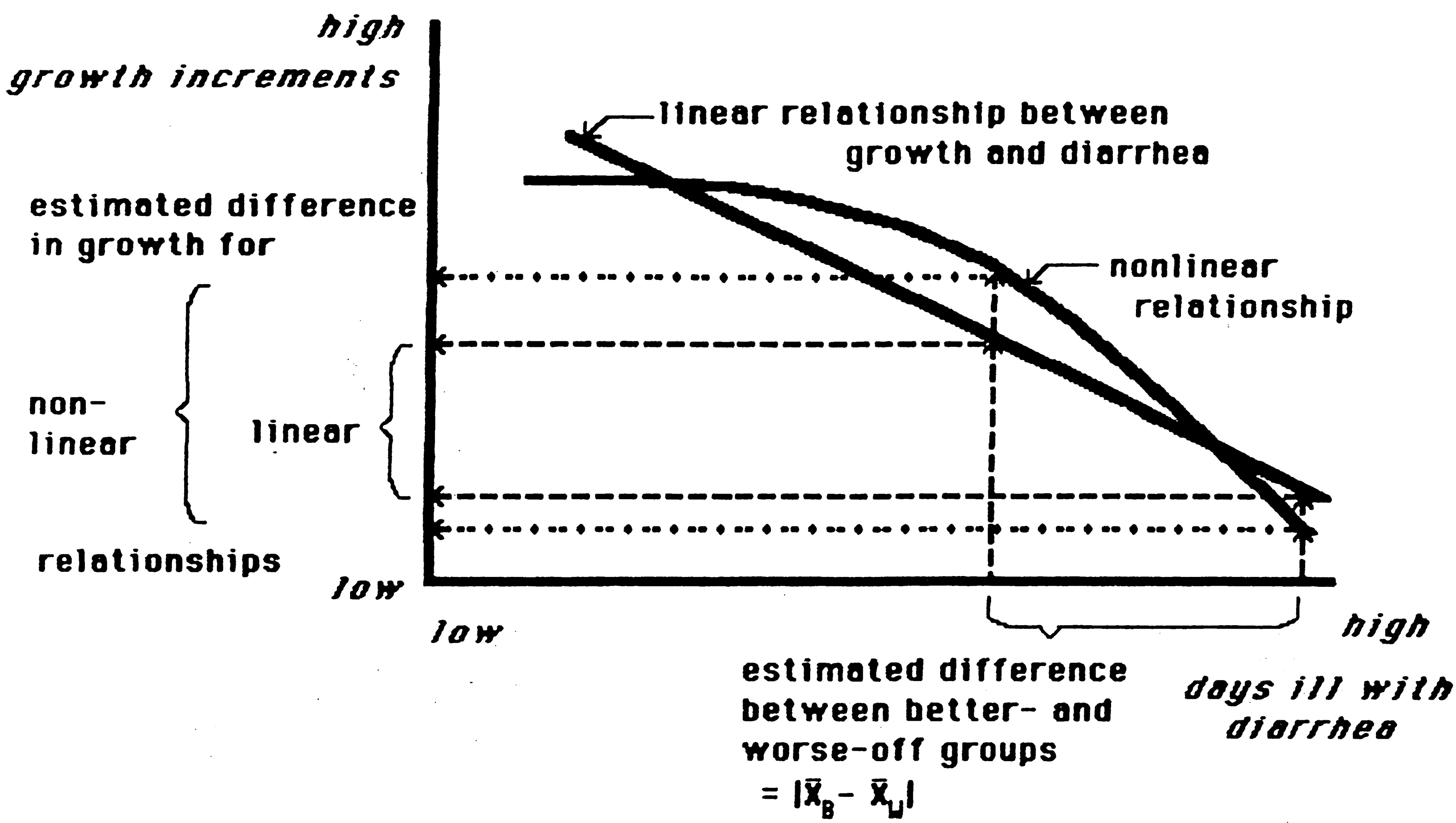

FIGURE 4: Relative responsiveness of growth versus diarrhea measurements

Children 18-24 Months of Age