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Modeling the Effects of Health Status and the Educational Infrastructure on the Cognitive Development of Tanzanian School Children

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Modeling the effects of health status and the educational infrastructure on the cognitive development of Tanzanian school children [1]

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This paper modeled the proximate determinants of the scores on cognitive and educational achievement tests and on school examinations of approximately 680 Tanzanian school children in a longitudinal random effects framework. The models incorporated the biological aspects by including the intensity of children's parasitic infections of hookworms and schistosomiasis, and anthropometric indicators, and the behavioral factors by taking into account children's school attendance and grade level, the socioeconomic factors, and the educational infrastructure. The empirical results showed the importance of children's health status, as approximated by height, hemoglobin concentration and C-reactive protein levels, for the test scores. The teachers' experience and work assignments were significant predictors of the scores on educational achievement tests. Overall, the empirical results indicated a preference for the use of educational achievement tests in impoverished settings because of children's familiarity with such procedures.

KEY WORDS Cognitive and educational achievement tests, school examinations, iron deficiency anemia, longitudinal data, children, Tanzania.

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A large number of children in developing countries fail to complete primary education. In Tanzania, for example, it was estimated that only 50% of the eligible children successfully competed primary school (International Bureau of Education, 1997). Because learning is a cumulative process, children dropping out of school are unlikely to pursue education and hence would not be a part of the skilled labour force that is essential for economic development (Bhargava, 2001). The likely factors hindering school completion include poor health status, an inadequate educational infrastructure, poverty drawing children into household and other tasks, and the lack of future work opportunities. Because child health and development are complex processes covering aspects that are analyzed in different disciplines, it is essential from a policy standpoint to use a common analytical framework for quantifying the relative magnitudes of the factors affecting child development. For example, while a hungry child is unlikely to comprehend the material presented in school, it is also the case that a poor educational environment may not stimulate even the adequately nourished children.

While informed policy decisions entail the use of elaborate information on factors affecting children's learning, researchers in different disciplines have underscored different dimension of child development. For example, certain psychologists have argued that intestinal parasites such as hookworms and schistosomiasis can affect the central nervous system (e.g. Watkins & Pollitt, 1997). While the neurological pathways remain unclear, the effects of anthelmintic treatment on children's scores on cognitive tests have been investigated in randomized trials (e.g. Dickson et al., 2000). The results have been ambiguous in part because the studies were conducted in a short time frame and also because there are complex interactions between children's health status, socioeconomic variables, and the educational infrastructure. Thus, for example, anthelmintic treatment can improve children's iron status (Bhargava et al. 2001a) that in turn can reduce sicknesses, and increase school attendance. If the school environment is stimulating, anthelmintic treatment can significantly enhance child development through a mechanism that is readily appreciated by behavioral and social scientists.

At a conceptual level, there are difficulties in focusing on a subset of indicators of child development, health status, educational infrastructure and socioeconomic variables. The limited resources available for longitudinal studies, however, enforce the choice of variables. While cognitive tests have been widely used as indicators of child development, there are potential difficulties in ensuring that children subsisting in poverty are acclimatized for participating in the tasks. When many of the relevant factors are accounted, the analysis of cognitive data on school children can provide useful insights (Bhargava, 1998). Further, children regularly take school examinations in subjects such as arithmetic, science, etc. While the scores on school examinations partly reflect teachers' capabilities (Goldstein & Thomas, 1996), children are familiar with the testing process. Educational achievement tests, such as those in sentence reading, spelling and arithmetic, are similar in spirit to school examinations but can be implemented by trained outside observers. Thus, a comparative analysis of the scores on cognitive and educational achievement tests and school examinations can afford insights into the proximate determinants of child development as well as into the usefulness of such measures.

The choice of variables reflecting children's health status and the educational infrastructure is also important. While anthropometric variables such height and weight are good indicators of nutritional status, the measurement of C-reactive protein provides a quantitative assessment of infection levels such as those due to malaria and HIV (van den Broek & Letsky, 1999). Because poor quality diets in developing countries typically supply low levels of micronutrients such as iron that is important for cognition (Lozoff, 1989, Pollitt, 1993), children's hemoglobin concentration is a useful health indicator. Socioeconomic information on the households, and measures of educational infrastructure such as teacher absenteeism, years of teaching experience, and work assignments are potentially important factors affecting learning. Moreover, school attendance is likely to differentially affect the scores on cognitive and educational tests and school examinations.

The analytical framework for modeling the development of Tanzanian school children

Children's cognitive development in poor societies is affected by their nutritional and health status, socioeconomic factors, and the educational infrastructure. Poverty can force parents to assign household tasks to children that may interfere with learning. In addition, intestinal parasitic infections such as hookworms and schistosomiasis, that are known to cause iron loss, may have an independent effect on the central nervous system. Even in an impoverished environment, however, a child must learn language in order to convey the basic needs to the adults (Vygotsky, 1987). By contrast, one might observe greater differences between children from poor and well-off households on tasks such as arithmetic that require a gradual acquisition of skills through instruction in school or at home.

Further, because learning is a cumulative process and children are periodically tested in school, the children performing poorly are likely to get discouraged from continuing school. Socioeconomic variables such as household incomes can make a critical difference in determining the duration for which such children stay in school. Moreover, health status is a multi-dimensional concept encompassing physical growth, iron status, sickness spells, and parasitic infections. The educational infrastructure is also likely to play an important role; in view of the plasticity of the human brain (Purves, 1988), some of the adverse effects of poor health can conceivably be offset by a stimulating environment. The empirical models for children's test scores should address such factors.

The potentially adverse effects of parasitic infections on the central nervous system can be incorporated in the models for test scores by including hookworm and schistosomiasis egg counts as explanatory variables. These factors may be especially relevant for the time taken in certain cognitive tests to complete tasks that require coordination between various skills. By contrast, parasitic infections may be less important for performance on academic achievement tests and school examinations, where school attendance and infrastructure could play a greater role. Thus, children's scores on cognitive and educational achievement tests and school examinations are likely to be differentially affected by measures of health status, socioeconomic variables and the educational infrastructure.

Among the behavioral aspects, the determinants of children's school attendance are of interest since poverty can interfere with regular attendance thereby reducing the exposure to learning activities. However, poor health status and an inadequate educational infrastructure can dilute the benefits of school attendance. Nevertheless, one would expect school attendance to be a predictor of the scores on educational achievement tests and school examinations. This need not be the case for cognitive test scores that could be more influenced by children's understanding of the instructions presented prior to the tests. Similarly, if school examinations cannot adequately assess children's knowledge due to a poor educational infrastructure (Bhargava, 1998), then school attendance may not be an important predictor of the scores on school examinations.

The empirical model

The empirical model incorporating the biological and behavioral aspects of children's test scores can be represented by 4 equations. Let $SchAtt_{it}$, Cog_{it}, $Educ_{it}$, and $SchExam_{it}$ be, respectively, the measurements for the i th child in time period t (i=1,...,n; t=1,2,3) on the proportion of school attendance, and the scores on cognitive tests, educational achievement tests, and school examinations. The respective empirical models can be represented by equation (1)-(4):

$$SchAtt_{it} = a_0 \text{(Constant)} + a_1 \text{(SES index)}_i + a_2 \text{(RESTDUM)}_i + a_3 \text{(C-reactive protein)}_{it} + a_4 \text{(Hemoglobin)}_{it} + u_{1it} \quad (1),$$

$$Cog_{it} = b_0 \text{(Constant)} + b_1 \text{(Grade)}_i + b_2 \text{(SES index)}_i + b_3 \text{(Hookworms)}_i + b_4 \text{(Schistosomiasis)}_i + b_5 \text{(Height)}_{it} + b_6 \text{(C-reactive protein)}_{it} + b_7 \text{(Hemoglobin)}_{it} + u_{2it} \quad (2),$$

$$Educ_{it} = c_0 \text{(Constant)} + c_1 \text{(Grade)}_i + c_2 \text{(SES index)}_i + c_3 \text{(Hookworms)}_i + c_4 \text{(Schistosomiasis)}_i + c_5 \text{(Height)}_{it} + c_6 \text{(C-reactive protein)}_{it} + c_7 \text{(Hemoglobin)}_{it} + c_8 \text{(SchAtt)}_{it} + u_{3it} \quad (3),$$

and

$$SchExam_{it} = d_0 \text{(Constant)} + d_1 \text{(Grade)}_i + d_2 \text{(SES index)}_i + d_3 \text{(Hookworms)}_i + d_4 \text{(Schistosomiasis)}_i + d_5 \text{(Height)}_{it} + d_6 \text{(C-reactive protein)}_{it} + d_7 \text{(Hemoglobin)}_{it} + d_8 \text{(SchAtt)}_{it} + u_{4it} \quad (4).$$

Here ($a_0,\ldots,a_7$, $b_0,\ldots, b_8$, $c_0,\ldots, c_8$, $d_0, \ldots, d_8$) are the regression coefficients, and u_{1it}, u_{2it}, u_{3it} and u_{4it} are random error terms that are discussed below. RESTDUM was an indicator variable that was set equal to one if the child reported "resting" as the activity before and after school. Note that model (2) was estimated for

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scores on 8 components of cognitive tests; models (3) and (4) were estimated for the scores in two time periods on 3 components of educational achievement tests and school examinations in 4 subjects, respectively. In addition to the explanatory variables in models (3) and (4), the average years of teacher experience and the number of work assignments in the child's grade were included as explanatory variables in the enlarged models that incorporated the school infrastructure; missing observations on 2 schools necessitated the separate estimation. Also, in model (2), school attendance was excluded because it was not a statistically significant predictor of the cognitive test scores.

Method

Participants

The study was conducted in 10 schools in the coastal area of Bagamoyo and Kibaha districts of Tanzania in 1997-8 (Partnership for Child Development, 2001). The schools were eligible if more than 100 children were enrolled in Grades 2-5 and were accessible by road during the rainy season. Children were eligible to participate if they were between 9-15 years old; children were excluded if the parent or guardian refused consent. The Institute of Child Health, London, UK, and the Tanzania Ministry of Health approved the study design. Due to the eligibility criteria, a total of 1232 children were observed 3 times in a 15-month interval. Approximately half the children were randomized into a treatment group against hookworms and schistosomiasis. Because the analysis in this paper excluded the data on treated children, the sample size was reduced to approximately 680 children.

Socioeconomic and demographic variables

The child's date of birth was recorded from the school register. Detailed background information was collected for the households. For example, the construction materials of the roof, walls, and the floor were recorded. The number of household possession such as bicycle, radio, and refrigerator were recorded. In addition, an index of socioeconomic status was constructed by summing up the households' scores on the quality of materials used for construction, furniture, etc.

Measures of children's health status

The children's weight, height, and mid-upper arm circumference were measured in each survey round. Electronic scales were used to measure weight to the nearest 0.1 kg. Two observations were taken on height using a portable stadiometer. The mid-upper arm circumference of the children's left arm was measured using a waxed paper insertion tape. In each survey round, nurses drew 2 milliliter of blood using sterilized syringes. Hemoglobin concentration was measured using a portable *photometer*. Ferritin and C-reactive protein were measured by sandwich ELISA (Partnership for Child Development, 2001).

Three urine samples were taken at the third survey round on the children during school hours; the children brought stool samples to the school using a supplied container. The schistosomiasis eggs were expressed per 10 milliliter of filtered urine as an indicator of infection intensity. Two sets of observations were averaged to produce a reliable estimate of egg count. Children's stool was tested for hookworms and for other helminth infections such as Ascaris lumbricoides and Trichuris trichiura. The hookworm eggs were counted and expressed as eggs per gram of stool.

Cognitive and educational tests and school examinations

The cognitive tests, adapted to the Tanzanian environment, consisted of several tasks measuring analytical and motor skills and were given to approximately half the children in the 3 survey rounds (Partnership for Child Development, 2001). Briefly, Digit Span (forward and backward) asked children to repeat strings of numbers after the examiner read them out. Corsi block is a visual-spatial analogue of the digit span forward test. The Stroop test measured the time taken to correctly fill in "ticks" and "crosses" into 48 boxes. The Grooved Pegboard tasks assessed motor skills by measuring the time for completion of tasks using the dominant and non-dominant hands. The Verbal fluency test asked the children to name as many foods and animals in one minute periods, with a point given for non-duplicate answers. Silly Sentences test asked the children for a "yes" or a "no" response to questions and recorded the number of correct answers; the Mean Response time in answering the questions correctly was analyzed. Lastly, children's Reaction time was measured in the tasks that entailed choosing the picture that matched the auditory signal.

The educational achievement tests were given in survey rounds 1 and 3 and consisted of a letter, word and sentence reading score in Kishwahili. This test was specially designed to measure children's comprehension and the scores were adjusted for incorrect answers. The Spelling test consisted of 50 questions. There were written and oral tests in arithmetic; the total arithmetic score was used in the analysis. The children's scores on school examinations during the terms were matched with the three time points of the survey rounds; the scores in arithmetic, English, Kishwahili, science, domestic science, geography, and civics were recorded. However, because many observations were missing in survey round 1, only the data from survey rounds 2 and 3 were analyzed.

Educational infrastructure

The enumerators visited the schools and recorded variables reflecting the infrastructure and teacher qualifications in 8 of the 10 schools. For example, the proportions of children in the various grades sitting on the floor were recorded. The number of teachers and their years of experience were recorded; number of blackboards, desks, chairs, pictures, textbooks, etc in the classroom was also recorded. In addition, the number of work assignments for each subject in all grades was investigated. The empirical analysis utilized indices based on this information. For example, the average number of years of teaching experience was constructed for each school. Similarly, the number of work assignment for each grade in the schools was constructed. Such variables reflected grade-specific aspects of the school infrastructure that appeared to be relevant for children's learning.

Statistical and econometric methods

The descriptive statistics were calculated using a standard statistical package (SPSS, 1999). However, the estimation of the empirical model given in equations (1)-(4) required the use of econometric methods. First, note that the errors affecting equations (1)-(4) are often decomposed into the simple random effects model as:

$$u_{it} = ä_i + v_{it} \quad (5),$$

where ä's are the children specific random effects and v's are independently distributed random variables with constant variances (Laird and Ware, 1982). The econometric estimation method assumed that the errors

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on equations (1)-(4) were independent across the children but correlated over time with a positive definite variance-covariance matrix. Thus, the random effects decomposition in equation (5) was a special case of our formulation. Because the observations were separated by unequal time intervals, we did not postulate dynamic or autoregressive models for the test scores (Bhargava, 1998).

Further, since the errors affecting school attendance in equation (1) may be correlated with the errors on equations (3) or (4), it was desirable to test if school attendance was an "endogenous" variable (i.e. correlated with the errors). The children specific random effects ($ä_i$) were a likely source of correlation. A methodology for estimation of longitudinal random effects models with endogenous explanatory variables was developed by Bhargava (1991). Briefly, when the explanatory variables are "exogenous", models such as equation (3) can be estimated by a two-step Generalized Least Squares method (Theil, 1971). If the model contains endogenous explanatory variables, the exogenous variables can be used as "instrumental variables" for predicting the endogenous variables. A Three Stage Least Squares type procedure can be used to estimate random effects models with endogenous explanatory variables. Under certain assumptions and for large n, the model parameters are consistently estimated and normally distributed. Also, one can test if some of the explanatory variables are correlated with the errors. A Fortran program to compute such models is available from the first author.

Results and Discussion

Descriptive statistics

The sample means of selected explanatory variables of the Tanzanian school children in the 3 survey rounds are presented in Table 1; the means of the scores on various components of cognitive and educational achievement tests and school examinations are in Table 2. Hookworm and schistosomiasis infections were widely prevalent in this population. For example, the hookworm eggs per gram of stool at percentiles 30, 40, 50, 60, 70, 80, 90, and 95 were, 35, 123, 228, 368, 632, 1022, 1972, and 3165, respectively. Thus, more than 30% of the children had over 400 eggs per gram of stool and were moderate to heavily infected with hookworms. Similarly, the schistosomiasis egg counts per 10 milliliter of urine at the above percentiles were

0.3, 1.0, 5.3, 29.3, 82.7, 226.2, 587.3, and 900.5, respectively. Again, approximately 30% of the children carried moderate to heavy schistosomiasis infections. The hemoglobin concentrations in grams per liter of blood at percentiles 10 through 90 were 99, 106, 110, 114, 116, 119, 122, 125, and 130, respectively. Thus, 60% of the children had hemoglobin concentration lower than 120 and suffered from iron deficiency anemia. Sample means of the scores on school examinations in arithmetic, science, geography and civics in survey rounds 2 and 3 are reported in Table 2; observations were missing for many children in survey round 1.

Empirical results for school attendance

The empirical results from estimating the random effect model presented in equation (1) for the logistic transformation of the proportion of time the child attended school (Cox, 1971) during each of the 3 survey rounds are in Table 3. The index of socioeconomic status, and the C-reactive protein and hemoglobin measurements were converted into natural logarithms to reduce heteroscedasticity (Nelson et al., 1989). The estimated coefficients of the transformed variables were thus the "elasticities" (percentage change in the dependent variable resulting from a 1% change in an independent variable). The results showed that children's socioeconomic status was a significant predictor of school attendance. There was additional information on children's activities prior to coming to school and on returning home from school. Children who reported mainly "resting" in these periods were likely to attend school more regularly, though the coefficient was not statistically significant.

The children's hemoglobin concentration was a significant predictor of school attendance. Hemoglobin concentration is increased by the intake of absorbable iron that is found in high proportions in animal products typically consumed by better-off households (Bhargava et al., 2001b); hemoglobin concentration is reduced by the intestinal parasitic loads (Bhargava et al., 2001a). Moreover, evidence on Kenyan children suggested that children with higher hemoglobin concentration were sick less frequently (Bhargava, 1999). Thus, the positive association between hemoglobin concentration and school attendance underscored the importance of adequate intakes of absorbable iron and for removing intestinal parasites. Controlling for children's hemoglobin concentration, however, hookworm and the schistosomiasis egg counts were not significant predictors of school attendance. The coefficient of C-reactive protein was estimated with a negative sign but was not statistically significant; infections such as malaria can elevate C-reactive protein levels.

Empirical results for the scores on cognitive tests

The results for the scores on digit span (forward and backward), Corsi block, time taken to complete the Stroop tasks, and the time for completing Grooved pegboard with the dominant hand are reported in Table 4. The results for the Grooved pegboard time using the non-dominant hand, scores on Verbal fluency, the Mean Response time for answering the Silly Sentences, and the Mean Reaction time are in Table 5. Except for the child's grade, all the variables were transformed into natural logarithms. The zero counts of hookworm and schistosomiasis eggs were set equal to one prior to the logarithmic transformation. Sensitivity analysis showed that this procedure was quite innocuous.

The main findings in Tables 4 and 5 were that children's grade and height were significant predictors of the scores on cognitive tests. The only exception was in the model for the Mean Reaction time where the child's grade was an insignificant predictor. Children's grade level broadly reflects their learning in school and was thus an expected predictor of cognitive function. However, the coefficient of school attendance was not significantly different from zero in all the 8 components of the cognitive test scores and hence school attendance was dropped from the models. Height is a good indicator of the long-term nutritional status and was a significant predictor in all models. However, the coefficient of body weight was not statistically different from zero in these models. Controlling for a child's height, body weight is a good measure of the medium-term nutritional status (Bhargava, 1994). Thus, the effects of short-term under-nutrition on cognitive test scores were not apparent in this population. Also, the index of socioeconomic status was not a significant predictor in Tables 4 and 5.

The C-reactive protein levels were significantly associated with the scores on digit span, Grooved pegboard dominant time, and the Mean Response and Reaction times. The prevalence of malarial parasites was high in this population; approximately 35% of the children were infected (Bhargava et al, 2001a). Because malarial parasites elevate C-reactive protein levels, it was likely that malaria was responsible for poor performance on these tasks. However, HIV can also elevate C-reactive protein levels though the children were not tested for HIV. Hemoglobin concentration was a significant predictor of the scores only on the Grooved pegboard using the dominant hand. In the remaining models, the coefficients of hemoglobin had the expected signs but were not significantly different from zero.

The coefficients for hookworm and schistosomiasis egg counts were mainly statistically insignificant. In the models for Grooved pegboard dominant time in Table 4 and the Mean Reaction time in Table 5, the coefficients of schistosomiasis were significant but estimated with the wrong signs. Lastly, the sample means of cognitive scores in Table 2 showed a slight increase in the scores over the survey rounds and a decline in the time taken to complete the tasks. The model in equation (2) was also estimated with indicator variables for survey rounds 2 and 3. The results confirmed significant increases in cognitive test scores over time. It seemed likely that there were improvements in children's performance because of "learning-by-doing" on the cognitive tasks.

Empirical results for the scores on educational achievement tests

The results for children's scores on sentence reading, (oral and written) arithmetic and spellings, using the data at two time points, are reported in Table 6. Because the scores on sentence reading were adjusted for wrong answers and some children made several mistakes, the scores were negative in some cases. The scores on total arithmetic and spellings were transformed into natural logarithms but the scores on sentence reading were modeled in levels. The children's grade level, index of socioeconomic status, height, and school attendance were significant predictors of all the three scores. The time spent in school is likely to enhance children's performance on tests that are similar in spirit to the material presented and examined in school. In all three models, the null hypothesis that the random effects affecting the test scores were uncorrelated with those affecting school attendance was rejected at the 5% level. The estimation method therefore treated school attendance as an endogenous variable for the results presented in Table 6.

Hemoglobin was a significant predictor of the scores on Sentence reading and spelling but was insignificant in the model for total arithmetic. The hookworm egg count was negatively associated with the scores on all three tasks and was significant in the models for Sentence reading and spelling; hemoglobin concentration was also significant in these models. By contrast, schistosomiasis egg counts were not significant in any of the three models. Thus, the intensity of hookworm infestation apparently had deleterious effects on children's performance on educational achievement tests even after controlling for the children's iron status approximated by their hemoglobin concentration.

There are some interesting comparisons between the results for the scores on cognitive and educational achievement tests. First, the proportion of time spent attending school was an insignificant predictor of the scores on all 8 components of cognitive tests but was significant for all three components of educational achievement tests. The correlation between the random effects and school attendance further indicated the need to jointly model the environmental factors affecting children's intellectual development. Second, hookworm intensity was not a significant predictor of cognitive test scores but was a significant predictor of the scores on two components of the educational achievement tests. While it is conceivable that hookworm infections affect the central nervous system, such effects may be obscured by the internal variation in cognitive data, possibly due to slow learning. Third, the index of socioeconomic status was estimated with negligible coefficients in the models for cognitive test scores but with large significant coefficients in all three components of the educational achievement tests. While the sample sizes were different for the cognitive and educational tests, the estimated coefficients in the models for the scores on educational achievement tests seemed more plausible. The implications of these findings are further discussed in the Conclusion.

Empirical results for the scores on school examinations

The results for children's scores on school examinations in arithmetic, science, geography, and civics in survey rounds 2 and 3 are presented in Table 7; the results for English, Kishwahili, and domestic science were similar and were suppressed to economize on space. The child's grade level was significantly negatively associated with the arithmetic score. This suggested a decline in children's performance in subjects requiring analytical skills that would eventually affect the decision to continue school. The index of socioeconomic status was a significant predictor of the examination scores. Although the coefficients of hookworm egg count were not significant in the four models, they were estimated with negative signs. The schistosomiasis egg counts were also estimated with negative signs and the coefficient was statistically significant in the model for the scores on arithmetic.

Children's height was a significant predictor of the scores in science, geography and civics. Hemoglobin concentration was a significant predictor of the scores on arithmetic. Height and hemoglobin concentration reflected the beneficial effects of diet quality on children's school performance. C-reactive protein was negatively associated with the scores in arithmetic and civics. In contrast with the results for the educational achievement tests, school attendance was an insignificant predictor of the scores in arithmetic and civics. For the scores in science and geography, the coefficients were significant but negative thereby indicating lower scores for children attending school more regularly. The last finding was in contrast with the results for the educational achievement tests (Table 6) and cast some doubt on the fairness of the scoring methods used in school examinations, possibly in certain grades within some schools.

Empirical results for the scores on educational achievement tests and school examinations controlling for the school infrastructure

Tables 8 and 9 present, respectively, the results for the scores on educational achievement tests and school examinations where the models controlled for teachers' years of experience and the number of work assignment in the grade. The sample sizes were lower than those used in Tables 5 and 6, respectively, because of missing data for 2 schools. In Table 8, teachers' experience was a significant predictor of the scores on total arithmetic; the number of work assignments was positively associated with the scores on Sentence reading. The proportion of school attendance was a significant predictor of the three scores. However, variables such as teacher absenteeism were not significant predictors in Table 8. The results for educational achievement tests in Tables 6 and 8 were similar except that, controlling for the school infrastructure, the index of socioeconomic status was statistically significant only for the scores on spelling in Table 8. Also, hemoglobin concentration was a significant predictor only for the scores on total arithmetic in Table 8. The reduction in sample size contributed to an increase in the respective standard errors of the estimated coefficients.

The results for school examinations in Table 9 showed that teacher experience and the work assignments were not significant predictors of children's performance in arithmetic, science, geography and civics. Socioeconomic status was a significant predictor of the scores in geography and civics. Height was a significant predictor of the scores in science, geography and civics in Tables 7 and 9. While the proportion of school attendance still had the wrong signs in the models for science and geography, the coefficients were no longer statistically significant. Overall, the results in Table 9 did not appear to provide additional insights into the role of teacher experience and work assignments for children's performance in school examinations.

Conclusion

This paper analyzed in detail a comprehensive longitudinal survey from the coastal regions of Tanzania on children attending primary schools. The broad analytical framework developed for the scores on cognitive and educational achievement tests and school examinations provided many important insights. For example, children's health status, as measured by their height, hemoglobin concentration and C-reactive protein levels, was an important predictor of performance on the tests. The empirical results underscored the importance of a good diet quality and the need to reduce morbidity, including the removal of intestinal parasites such as hookworms and schistosomiasis, for enhancing child development. Furthermore, regular school attendance was important for the scores on educational achievement tests. Because school attendance was itself affected by the households' socioeconomic status, interventions such as subsidizing the poorest households for regularly sending children to school and placing greater emphasis on the completion of school assignments are likely to be beneficial for children's intellectual development.

Because the biological and behavioral pathways were incorporated in the analysis, the empirical results also provided methodological insights. For example, the models for test scores included children's hookworms and schistosomiasis loads that have been argued to affect the central nervous system and also took into account the role of socioeconomic factors and school attendance. In general, the educational achievement tests are closer in spirit to the material taught and examined in the classroom and can be administered by trained staff. By contrast, the Tanzanian children's understanding of the tasks on cognitive tests was not affected by school attendance. While the models for the scores on school examinations identified some of the proximate determinants of children's learning, the results appeared to be influenced to some degree by teacher capabilities and the school infrastructure. Consequently, educational achievement tests are likely to be suitable instruments for assessing children's learning in impoverished settings. An allocation of resources to health and education sectors based on children's performance on educational achievement tests is likely to attain the desired goals.

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Table 1

Sample means and standard deviations of selected variables in 3 survey rounds of Tanzanian school children[1]

Variable	Round 1	Round 2	Round 3
Age, months	146.08∀ 14.57		
Grade	3.09∀ 1.08		
Socioeconomic status index	62.15∀ 5.75		
Hookworms[2] , eggs per gram eggs per gram of stool	-	-	727.1∀1378
Schistosomiasis[2], eggs per 10 ml urine	-	-	189.6∀500.1
Hemoglobin, grams per liter blood	115.22∀12.72	113.33∀11.92	117.18∀13.80
C-reactive protein, milligrams per deciliter blood	2.43∀3.77	2.11∀3.47	2.10∀3.23
Height, meters	1.37∀0.91	1.39∀0.90	1.43∀0.90
Weight, kilograms	30.96∀6.45	31.96∀6.68	35.22∀7.62
Proportion school attendance	0.887∀0.10	0.887∀0.14	0.872∀0.17

[1] Values are means ∀ SD; n=662. [2] Measured in survey round 3 only.

Date: March 2001

Table 2

Sample means of scores on the components of cognitive and educational achievement tests and school examinations of Tanzanian school children[1]

Variable	Round 1	Round 2	Round 3
		Cognitive tests[2]	
Digit span	11.57∀3.07	12.27∀2.80	12.98∀2.94
Corsi block	9.96∀2.02	10.62∀2.19	11.31∀2.26
Stroop	40.33∀8.52	35.51∀7.87	32.90∀6.35
Pegboard dominant time[3]	78.17∀31.86	64.67∀17.42	59.48∀11.04
Pegboard non-dominant time	94.24∀37.92	79.94∀28.54	72.27∀25.00
Verbal fluency	27.48∀8.08	29.77∀8.39	31.30∀8.20
Mean Response time	0.66∀0.22	0.63∀0.22	0.59∀0.13
Mean Reaction time	3.79∀0.30	3.67∀0.23	3.57∀0.21
		Educational achievement tests[4]	
Sentence reading	26.06∀15.51	-	37.59∀14.23
Total arithmetic	24.47∀5.41		27.34∀5.97
Spelling	35.68∀16.63	-	42.01∀14.77
		School examinations[5]	
Arithmetic	-	49.88∀24.60	34.32∀22.65
Science	-	48.60∀21.53	44.15∀20.59
Geography	-	47.85∀22.44	45.04∀18.87
Civics	-	46.28∀22.92	43.35∀18.53

[1] Values are means ∀ SD. [2] n=413. [3] Time is in seconds. [4] Educational tests were given in survey rounds 1 and 3; n=680. [5] Many observations were missing for school examinations in survey round 1; n=373.

Table 3

A longitudinal random effects model for the logistic transformation of the proportion of school attendance of Tanzanian school children in 3 survey rounds explained by socioeconomic variables, infections, and hemoglobin[1]

Dependent variable	Proportion of school attendance	
Independent variable	Coefficient	SE
Constant	-9.636*	2.361
Socioeconomic status, index	2.103*	0.500
Rest before and after school[3]	0.254	0.175
C-reactive protein, mg/dL	-0.028	0.028
Hemoglobin	0.750*	0.331

[1] Values are slope coefficients and standard errors; n=680.
[2] The dependent and independent variables were in natural logarithms.
[3] 1=YES; 0=NO.
* $p<0.05$.

Date: March 2001

Table 4

Longitudinal random effects models for Tanzanian children's scores on cognitive tests in 3 survey rounds explained by socioeconomic and anthropometric variables, infections, and hemoglobin[1]

Dependent variable	Digit span (forward+ backward)		Corsi block		Stroop (forward+ backward)		Pegboard dominant time	
Independent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-2.654*	0.997	-1.000	0.816	9.820*	0.719	9.717*	0.982
Grade	0.034*	0.012	0.018*	0.009	-0.042*	0.008	-0.034*	0.013
Socioeconomic status	-0.062	0.136	-0.102	0.102	-0.110	0.102	-0.227	0.144
Hookworms, epg	0.0004	0.004	-0.003	0.003	-0.002	0.003	-0.004	0.004
Schistosomiasis, ep10ml	0.003	0.004	0.004	0.003	0.0007	0.003	-0.013*	0.005
Height, m	1.048*	0.166	0.691*	0.139	-1.058*	0.122	-0.724*	0.164
C-reactive protein, mg/dL	-0.010*	0.005	-0.003	0.005	0.004	0.003	0.008*	0.004
Hemoglobin, g/L	0.023	0.072	0.064	0.063	-0.080	0.051	-0.168*	0.068

[1] Values are slope coefficients and standard errors, n=359.[2] Except for Grade, all variables were in natural logarithms. * p<0.05

Table 5

Longitudinal random effects models for Tanzanian children's scores on cognitive tests in 3 survey rounds explained by socioeconomic and anthropometric variables, infections, and hemoglobin[1]

Dependent variable	Pegboard non-dominant time		Verbal fluency		Mean Response time		Mean Reaction time	
Independent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	10.704*	1.048	-3.646*	1.160	9.503*	1.040	10.074*	0.286
Grade	-0.031*	0.013	0.029*	0.014	-0.035*	0.013	-0.006	0.004
Socioeconomic status	-0.212	0.150	-0.078	0.160	0.196	0.145	0.079	0.042
Hookworms, epg	-0.007	0.005	0.002	0.005	-0.005	0.005	0.000	0.001
Schistosomiasis, ep10ml	-0.005	0.005	0.008	0.005	0.002	0.005	-0.002*	0.001
Height, m	-0.948*	0.177	1.343*	0.194	-0.633*	0.176	-0.417*	0.048
C-reactive protein, mg/dL	-0.002	0.005	0.0001	0.006	0.013*	0.005	0.004*	0.001
Hemoglobin, g/L	-0.120	0.745	0.115	0.086	-0.133	0.077	-0.020	0.020

[1] Values are slope coefficients and standard errors, n=359.[2] Except for Grade, all variables were in natural logarithms. * $p<0.05$

Table 6

Longitudinal random effects models for Tanzanian children's scores on educational achievement tests in 2 survey rounds explained by socioeconomic and anthropometric variables, hemoglobin and school attendance[1]

Dependent variable	Sentence reading		Total arithmetic		Spelling	
Independent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-488.941*	36.944	-2.831*	0.657	-13.552	1.644
Grade	5.729*	0.416	0.097*	0.007	0.117*	0.020
Socioeconomic status	3.707*	4.713	0.172*	0.082	0.709*	0.233
Hookworms, epg	-0.387*	0.142	-0.002	0.002	-0.013*	0.007
Schistosomiasis, ep10ml	-0.107	0.149	-0.001	0.003	0.005	0.007
Height, m	92.137*	6.163	0.868*	0.112	2.554*	0.265
C-reactive protein, mg/dL	-0.362	0.245	-0.001	0.004	-0.002	0.009
Hemoglobin, g/L	6.952*	2.954	0.152*	0.052	0.249*	0.123
Proportion school attendance	0.512*	0.211	0.010*	0.004	0.019*	0.007
Chi-square statistic[3]	8.83*		11.18*		10.53*	

[1] Values are slope coefficients and standard errors, n=680.[2] Sentence reading scores and Grade were in levels and the remaining dependent and independent variables were in natural logarithms.
[3] Chi-square test for the exogeneity of proportion school attendance, df=2. * $p<0.05$

Table 7

Longitudinal random effects models for Tanzanian children's scores on school examinations in 2 survey rounds explained by socioeconomic and anthropometric variables, hemoglobin and school attendance[1]

Dependent variable	Arithmetic		Science		Geography		Civics	
Independent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-6.046	3.837	-9.429*	3.521	-4.652	2.710	-11.562*	2.954
Grade	-0.184*	0.049	0.058	0.047	-0.004	0.035	-0.071	0.038
Socioeconomic status	1.234*	0.439	1.272*	0.423	0.739*	0.310	1.202*	0.340
Hookworms, epg	-0.012	0.014	-0.009	0.013	-0.006	0.010	-0.002	0.011
Schistosomiasis, ep10ml	-0.030*	0.014	-0.001	0.014	-0.018	0.010	-0.018	0.011
Height, m	1.018	0.657	1.336*	0.600	1.121*	0.465	1.992*	0.507
C-reactive protein, mg/dL	-0.059*	0.025	-0.032	0.021	-0.004	0.018	-0.037*	0.018
Hemoglobin, g/L	0.056*	0.292	0.032	0.021	-0.006	0.200	0.151	0.203
Proportion school attendance	0.001	0.018	-0.031*	0.015	-0.041*	0.017	-0.011	0.012
Chi-square statistic[3]	4.69		4.36		7.30*		0.39	

[1] Values are slope coefficients and standard errors, n=294.[2] Except for Grade, all variables were in natural logarithms. [3] Chi-square test for the exogeneity of Proportion school attendance, df=2. * $p<0.05$

Table 8

Longitudinal random effects models for Tanzanian children's scores on educational tests in 2 survey rounds explained by socioeconomic and anthropometric variables, and school attendance and infrastructure[1]

Dependent variable	Sentence reading		Total arithmetic		Spelling	
Independent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-484.127*	46.268	-2.120*	0.815	-14.012	2.177
Grade	6.025*	0.559	0.109*	0.010	0.132*	0.028
Socioeconomic status	7.432	6.592	0.093	0.114	0.743*	0.342
Teacher experience	0.195	0.302	0.013*	0.005	0.012	0.016
Work assignments	0.057*	0.028	0.0003	0.0005	0.002	0.001
Hookworms, epg	-0.280	0.169	-0.001	0.003	-0.009	0.009
Schistosomiasis, ep10ml	0.126	0.188	-0.0002	0.003	0.006	0.010
Height, m	87.996*	7.325	0.741*	0.131	2.543*	0.329
C-reactive protein, mg/dL	0.012	0.285	-0.001	0.005	0.006	0.011
Hemoglobin, g/L	5.755	3.418	0.157*	0.059	0.262	0.149
Proportion school attendance	0.605*	0.247	0.020*	0.004	0.033*	0.008

[1] Values are slope coefficients and standard errors, n=507.[2] Sentence reading and Grade were in levels and the remaining variables were in natural logarithms; Chi-square statistics were suppressed * $p<0.05$

Table 9

Longitudinal random effects models for Tanzanian children's scores on school examinations in 2 survey rounds explained by socioeconomic and anthropometric variables, and school attendance and infrastructure[1]

Dependent variable	Arithmetic		Science		Geography		Civics	
Independent variable	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Constant	-6.342	4.677	-9.205*	4.389	-8.449*	3.135	-11.988*	3.722
Grade	-0.209*	0.060	0.099	0.058	0.012	0.040	-0.042	0.047
Socioeconomic status	0.914	0.607	0.609	0.587	0.892*	0.409	0.979*	0.479
Teacher experience	0.380	0.313	0.497	0.303	0.247	0.211	-0.056	0.247
Work assignments	-0.0001	0.002	0.0004	0.002	-0.001	0.002	-0.003	0.002
Hookworms, epg	-0.006	0.016	0.002	0.016	-0.0002	0.011	0.002	0.013
Schistosomiasis, ep10ml	-0.041*	0.017	-0.010	0.017	-0.014	0.012	-0.019	0.014
Height, m	1.140	0.753	1.555*	0.707	1.625*	0.507	2.398*	0.605
C-reactive protein, mg/dL	-0.069*	0.029	-0.027	0.025	-0.005	0.019	-0.033	0.021
Hemoglobin, g/L	0.072	0.339	0.220	0.300	-0.239	0.220	0.034	0.255
Proportion school attendance	0.021	0.020	-0.020	0.017	-0.009	0.013	-0.017	0.015

[1] Values are slope coefficients and standard errors, n=218.[2] Except for Grade, all variables were in natural logarithms; Chi-square statistics were suppressed. * $p<0.05$