Exploiting Externalities to Estimate the Long-Term Effects of Early Childhood Deworming[*]

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Abstract

I investigate whether a large-scale deworming intervention aimed at primary school pupils in western Kenya had long-term effects on young children in the region, exploiting positive externalities from the program to estimate the impact on younger children who did not receive treatment directly. I find large cognitive effects—equivalent to half a year of schooling—for children who were less than one year old when their communities received mass deworming treatment. I also find modest positive effects on stature. Because mass deworming was administered through schools, I also estimate effects among children who were likely to have older siblings in school to receive the treatment directly; in this subpopulation, effects are twice as large.

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1 Introduction

Shocks in early childhood can permanently reduce an individual's potential lifetime health, earnings, and cognition. Several variations of this idea, as hypothesis or as stylized fact, are well-known. The lasting effects of nutrition shocks a child experiences before birth are grouped under the "fetal origins" hypothesis (Almond and Mazumder 2005). More generally, important times during early childhood for cognitive development are referred to as "critical" and "sensitive" periods (Knudsen 2004). Yet because of the demanding longitudinal data required, very few studies have successfully documented these patterns; fewer still are able to establish causal relationships between external influences early in life and long-term outcomes.

However scant, the available evidence suggests that the phenomenon is real, and that the effects are dramatic. One panel study shows that reading test quartiles at age seven predict 20 percent differences in adult wages in Great Britain (Currie and Thomas 1999); another, that performance at age four on a delay-of-gratification task is a strong predictor of high school SAT score (Shoda, Mischel, and Peake 1990). Though these patterns survive the inclusion of important statistical controls, they may only illustrate simultaneous causation. Perhaps these results only appear because the same forces that determine performance in early childhood—parenting and genetics, for example—continue to determine outcomes in the decades that follow. A different strand in this literature solves this problem, showing that specific exogenous environmental shocks have lasting repercussions when they occur in early childhood: in Indonesia, beneficial rains in the year of a girl's birth increase her adult height by more than half a centimeter, and raise her eventual educational attainment and wealth (Maccini and Yang 2009); in Zimbabwe, drought and civil war during the first two years of a child's life reduce his eventual height and educational attainment (Alderman, Hoddinott, and Kinsey 2006). In contrast, shocks that occur later in life do not appear to have significant impacts on long-run outcomes.

Though extreme shocks periodically affect a small fraction of the population, much of the world is afflicted by mild forms of disease. Less is known about whether such conditions, more easily addressed by human intervention, can permanently change outcomes in this way. One non-lethal disease very prevalent among children around the world is intestinal parasites. Helminths (worms) infect more than one billion people worldwide: predominantly young children in Asia and Sub-Saharan Africa (Hotez, *et al.* 2006). These infections are almost never fatal, but they directly cause anemia and listlessness, and may result in chronic symptoms (Bleakley 2007). A variety of studies have shown gains in health, cognition, and school attendance among school-age children given deworming medication; current research suggests that deworming medication may be one of the most cost-effective possible ways to increase school attendance and improve adult outcomes (Bundy, *et al.* 2009). Thus far, school-age children have been emphasized in studies of deworming because they are known to host the highest numbers of parasites (Bundy 1988). However, very recent studies reviewed by Albonico, *et al.* (2008) also document child health improvements in response to early childhood deworming. Despite promising short-term results, no study to date has shown whether early childhood deworming can have lasting benefits.

In this paper, I present the first evidence on the long-term effects of reducing helminth infection in early childhood by exploiting externalities from a randomized deworming intervention in Kenya. Though it was aimed only at school-age children, this kind of community-based deworming has large epidemiological spillovers both on other children (Miguel and Kremer 2004) and on others in the community (Bundy, *et al.* 1990). Taking advantage of these spillovers, I gathered new data in 2009 and 2010 in order to compare children who were in their first years of life at the time that treatment started in their community to children from the same cohort in untreated communities.

I find large effects on cognitive performance equivalent to half a year of schooling, as well as improvements in physical stature, more than ten years after the original intervention. Effects are strongest among those who were likely to have an older sibling in school at the time of the original intervention, as one might expect from an epidemiological perspective. My results support the theories that sensitive periods in early childhood are essential for physical and cognitive development, and that inexpensive actions are available that can increase human capital formation for millions of children around the world.

The remainder of this paper is organized as follows: In Section 2, I discuss the nature of the disease and the original intervention in Kenya; in Section 3, I provide details on the new data collection undertaken in 2009 and 2010; Section 4 presents the results of my analysis in light of the existing literature; and Section 5 concludes.

2 Background

A handful of helminth species are responsible for infecting between one and two billion people (Hotez, *et al.* 2006): schistosomes (*Schistosoma mansoni*, *haematobium*, and variants); and soil-transmitted "geohelminths:" roundworm (*Ascaris lumbricoides*), whipworm (*Trichuris trichiura*), and hookworm (*Necator americanus* and *Ancylostoma duodenale*). Several of these species are endemic in western Kenya, and though these infections can be addressed inexpensively with existing drugs, they usually go untreated.[1] In this setting, between 1998 and 2001, Miguel and Kremer (2004) randomly phased in deworming drugs to a group of 73 primary schools in western Kenya, in the "Primary School Deworming Project," PSDP. The program both reduced infections and increased school attendance. Only schoolchildren were dewormed, but the authors found large spillovers within the community: children in dewormed areas who were not actually given medication still received nearly 60% of the benefits of direct deworming. This is consistent with evidence from Montserrat, where mass deworming of children aged 2-15 reduced parasitic loads in adults who received no medication (Bundy, *et al.* 1990). Thus far, the effects of the intervention in Kenya have included gains of approximately 1cm in height, and 1kg in weight, as well as some preliminary evidence of increased rural to urban migration (Baird 2007). Cognitive and academic outcomes have yet to differ between treated and untreated groups.

Part of the reason may be that for some children (or some outcomes), this intervention came too late: the first two or three years of life are thought to represent crucial phases for both physical and cognitive development (Grantham-McGregor, *et al.* 2007, Knudsen, *et al.* 2006); nutrition shocks and changes to environmental stimuli in this period matter much more than they do later in life.[2] Two recent studies use rainfall changes to measure this

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[1] Albendazole and mebendazole are anti-geohelminth medications, effective against hookworm, roundworm, and whipworm. Schistosomiasis is usually treated with a different medication, praziquantel.

[2] Windows during which such outside influences have especially strong effects are referred to as "sensitive" periods (Knudsen 2004); when the consequences are not only large, but also permanent, these periods are referred to as "critical." But because "critical" and "sensitive" periods differ across cognitive faculties (Grantham-McGregor, *et al.* 2007, Knudsen, *et al.* 2006); I remain agnostic on whether de-worming

effect. Hoddinott and Kinsey (2001) find that children in Zimbabwe who are malnourished between the ages of one and two because of a drought remain permanently 1.5-2 cm shorter than their counterparts who were not exposed to the same conditions; older children exposed to the drought do not seem to suffer long-term harm. Maccini and Yang (2009) investigate long-term effects of good rainfall on children in Indonesia, and find that girls born in an area receiving 20 percent more annual rainfall than usual gain an additional 0.57cm in adult height, and complete an additional 0.22 grades of school, compared to children whose regions did not receive such beneficial rains.[3] Rainfall in other years had no significant long-term consequences.

Because the intervention for schoolchildren in Kenya had such large spillover effects, I hypothesize that children who were not yet old enough to attend school also garnered benefits. Because of their age at the time of the intervention, I further hypothesize that these younger cohorts may have been more sensitive to the intervention than the older children who actually received the drugs. Until recently, however, younger children were not thought to benefit substantially from deworming, because their parasitic load is typically much lower than it is in older children.

Several very recent studies demonstrate links between early childhood de-worming and health, summarized by Albonico, *et al.* (2008). Four studies in East Africa all found short-term health gains; among these, Alderman *et al.* (2006) found that de-worming brings about weight improvements in pre-school-age children in Uganda, in a district that borders the PSDP study area around Lake Victoria. Children in the Uganda study were between 1 and 7 years old, but the study did not disaggregate effects by age; however, the study by Stoltzfus *et al.* (2004) in Zanzibar did. They show that children who were treated when less than 30 months old gained the most. Within this young cohort, incidence of mild wasting[4] was cut nearly in half, from 36% in the control group to 18% in the treated group; older children did not improve nearly as much. The authors took note of this surprising aspect of their results: "The benefits thus occurred in the age group at highest risk for anemia and

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could intervene in a particular "critical" period, relying instead on evidence that analogous early childhood interventions had substantial effects on health and education.

[3] Rainfall shocks at age two have similar (though statistically insignificant) effects on both outcomes.

[4] *Mild wasting:* having weight-for-height worse than one standard deviation below average, $WHZ < -1$

growth retardation, but in the age group with the lowest intensity of helminth infections."

3 Data collection, 2009-1010

In 2009 and 2010, a field team in Kenya collected height, weight, migration and cognitive data from more than 20,000 children at the 73 deworming project schools in Samia and Bunyala districts of Kenya's Western Province. Summary statistics are shown in Table 1. Every child between the ages of 8 and 15 at these schools was included in the study, so that the cohort-by-cohort effects could be measured.

The randomization of the original deworming project at the community level allows me to use the earlier design for estimation: for example, in communities where deworming began in 1998, the pupils I find in 2009 at age 11 began experiencing the effects of community deworming at age zero. Pupils I find in 2009 at age 11 in other communities, where deworming began in 1999, for example, only began experiencing the effects of community deworming at age one. Because deworming started in different communities at different times, I can control for age at observation separately from age at treatment.

In-migration to these communities in response to Kenya's 2008 post-election violence left school populations inflated with recent migrants from urban areas; for my results, I exclude those migrants from all regressions, since they were not present in these communities at the time of deworming in the late 1990s. Out-migration is much less of a concern, since these rural areas are moderately ethnically homogeneous, and did not experience notable conflict. In Panels B and C of Table 1, I restrict attention to the sample of non-migrants. In Panels D and E, I further restrict the sample to those for whom a cognitive survey was carried out. Because the cognitive survey takes roughly ten times as long as anthropometric measurement, the cognitive outcomes were gathered only for a random subsample of respondents. Panel E shows that the characteristics of the respondents sampled for cognitive surveys do not differ from the characteristics of all respondents.

The cognitive module included two measures of "verbal fluency," in which children name as many items in a category as they can in one minute. The first category is foods; the second is animals. The Peabody Picture Vocabulary Test measures "receptive vocabulary," in which children point to one of four pictures that best matches a word that has been read aloud to them. There are eighteen levels of the test, each with twelve words; respondents proceed up through the levels until they make nine mistakes in a single level. For reasoning, I use the 12-question Set B of J. C. Raven's Progressive Matrices, a series of puzzles commonly used to measure of general intelligence.[5] For short-term memory, I use forward and backward digit-spans of increasing length. I provide raw means and standard deviations in Table 1, but for all regressions, I consider standardized versions of these cognitive measures, each re-scaled to have mean zero and standard deviation one.

4 Results

Results are shown in Tables 2 through 7. In Table 2, I summarize effects by comparing children whose communities were dewormed before they reached age 2 (first row) or while they were two years old (second row) to children whose communities were dewormed later (the excluded group). Because of the design of the original intervention, I can include school, age, and gender fixed effects in the regression. In odd-numbered columns, I use all non-migrant observations; in even-numbered columns, I restrict the sample to children who had at least three older siblings attend the same primary school: these are the children likely to have experienced the largest spillover effects. In this specification, I estimate that early community deworming treatment results in an additional 0.5cm in height, a 6-percentage-point reduction in stunting, and an improvement of varying magnitudes on several standardized cognitive outcomes. In the restricted sample, the effects are roughly twice as large in each case. Estimated effects at age two are generally smaller than effects of treatment before age two. These estimates may be thought of as lower bounds, because even the excluded (comparison) group received treatment starting at age three and later, and is still likely to have experienced some beneficial effects.

In Table 3, I split the effect by deworming cohort. Effects appear to be of a similar magnitude if children are born into dewormed communities (the first three rows); they are positive and slightly smaller if deworming arrives in the first year of life, and smaller still in

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[5] See discussion in Cattell (1971) and Raven (1989) of the matrices and what they measure.

the second year of life. Because the samples in each cohort are smaller than when pooled, standard errors widen compared to Table 2.

In these first two results tables, the inclusion of school fixed effects leaves very few observations in each school-gender-age cell, particularly for cognitive outcomes. Similar patterns are shown in Tables 4 and 5, this time without school fixed effects. In Table 4, I include deworming at age two in the comparison (excluded) group, but each cohort is again shown separately in Table 5.

In Tables 6 and 7, I break down the effect on the first principal component of cognitive tests (shown in columns (9) and (10) of previous tables) into effects on the six constituent tests. Though all the signs are positive, reasoning ability measured by Raven's Matrices shows the strongest pattern: deworming treatment before age two increases performance ten years later by 0.23 standard deviations; the effect rises to 0.38 standard deviations if an older sibling was likely to be attending the treatment school.

Interpretation of coefficients on cognitive tests is clarified in Tables 8 through 11. The first column of Table 8 shows the weights on each outcome that yield the first principal component used in the analysis. Weights are almost equal across the different cognitive outcomes.[6] Correlations among cognitive measures are shown in Table 9: all are positive. The relationships between cognitive performance, age, and grade in school are shown in Tables 10 and 11. In the cross-section, coefficients on grade in school are typically one third larger than the coefficients on age, since pupils tend to repeat one grade out of every three. Conditional on grade in school, older children perform worse, since they have typically chosen to repeat grades more frequently.

The main cognitive effect of 0.182 standard deviations on the first principal component (shown in Column 9 of Table 4) is thus equivalent to roughly half a grade in school, since a grade in school is associated with 0.38 standard deviations on the same outcome (shown in Column 2 of Table 10). The Raven's Matrices effect of 0.233 standard deviations (shown in Column 11 of Table 6) is equivalent to roughly a grade in school (shown to be 0.241 standard deviations in Column 11 of Table 11). For the respondents likely to have older

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[6] The lowest weight is for "Verbal Fluency: Foods," perhaps the noisiest measure because it was the first exercise in the cognitive module. Low R^2 in Tables 6 and 7 for this outcome also speak to its relative noisiness.

siblings in the treated school (shown in Column 10 of Table 4, and Column 12 of Table 6, for example), effects are roughly twice as large.

4.1 Discussion of results

Others have also found effects of deworming on cognition, though typically only in the short term. An observational study by Jukes, *et al.* (2002) investigated the relationship between cognitive function and helminth infections among Tanzanian schoolchildren, and found that after controlling for potential confounds, heavy schistosome infection was associated with lower performance on tests of short-term memory, reaction time, and information processing. A double-blind medical trial by Nokes, *et al.* (1992) found that the administration of albendazole led to immediate gains in memory skills in a population of Jamaican schoolchildren infected with whipworm and roundworm, and an experimental de-worming study with Tanzanian schoolchildren in the same region as the 2002 observational study also found cognitive gains in response to de-worming (Grigorenko, *et al.* 2006).

That I find effects mainly on reasoning and vocabulary rather than memory speaks to the differences between slowed cognitive development and the more immediate cognitive impairments brought about by concurrent disease. Memory improves with age, but seems to depend less on health in early child development. Reasoning and vocabulary both show long term responses to improved health in early childhood.

Effects on stature appear to be sensitive to the specification; as this is preliminary work, refinements that remove errors from the recorded data may help clarify this issue.

5 Conclusion

In this study, I measure the effect of deworming spillovers during early childhood. I find improvements in cognitive performance equivalent to half a year of schooling, as well as a reduction in stunting. Effects are twice as large for children with an older sibling likely to have received deworming medication directly. This bolsters theories of sensitive periods for physical and cognitive development, and provides evidence that an inexpensive intervention can benefit children immensely at this time.

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Table 1: Summary Statistics

Panel A: Characteristics, unconditional			
CHARACTERISTIC	MEAN	STANDARD DEV.	N
Age	11.511	(1.949)	20251
Female	0.510	(0.500)	19753
Height (cm)	141.688	(12.681)	19988
Ever migrated	0.308	(0.462)	20251
Panel B: Characteristics, conditional on non-migration and complete data			
Age	11.422	(1.947)	13713
Female	0.499	(0.500)	13713
Height (cm)	141.123	(12.754)	13700
Stunting (WHO 2007 HAZ< -2)	0.219	(0.414)	13670
Older siblings at same school	1.447	(1.596)	13713
At least 3 such siblings	0.223	(0.416)	13713
Panel C: Deworming cohort, conditional on non-migration and complete data			
Deworming before age -1	0.167	(0.373)	13713
Deworming starting at age -1	0.115	(0.319)	13713
Deworming starting at age 0	0.129	(0.335)	13713
Deworming starting at age 1	0.144	(0.351)	13713
Deworming starting at age 2	0.151	(0.358)	13713
Deworming starting after age 2	0.294	(0.456)	13713
Panel D: Cognitive data, conditional on non-migration and complete data			
Verbal Fluency: Foods	9.250	(2.984)	2185
Verbal Fluency: Animals	8.860	(3.235)	2185
Vocabulary: PPVT max level	6.017	(3.299)	2183
Reasoning: Raven's Matrices	3.620	(1.931)	2184
Memory: Digit Span Forwards	3.343	(1.736)	2165
Memory: Digit Span Backwards	0.958	(1.236)	2134
Panel E: Characteristics, conditional on non-migration and ***cognitive*** *data*			
Age	11.549	(1.918)	2134
Female	0.494	(0.500)	2134
Height (cm)	141.826	(12.986)	2131
Stunting (WHO 2007 HAZ< -2)	0.216	(0.412)	2131
Older siblings at same school	1.459	(1.628)	2134
At least 3 such siblings	0.223	(0.416)	2134

Table 2: All results 2010 and 2009, saturated, main effect indicator

	Outcome									
	Height		Stunting		PPVT		Raven's Matrices		Cognitive PC1	
	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs
Deworming Indicator	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Before age 2	0.582*	1.167**	-0.033*	-0.064**	0.157*	0.322*	0.248***	0.569**	0.128	0.356*
	(0.333)	(0.59)	(0.019)	(0.031)	(0.085)	(0.18)	(0.09)	(0.227)	(0.085)	(0.207)
Age 2	0.352	0.614	-0.024*	-0.007	0.004	-0.052	0.065	0.218	-0.007	0.255
	(0.272)	(0.495)	(0.014)	(0.027)	(0.086)	(0.178)	(0.082)	(0.194)	(0.082)	(0.185)
Observations	13700	3057	13670	3053	2183	494	2184	493	2123	474
R^2	0.691	0.709	0.054	0.073	0.338	0.412	0.174	0.283	0.333	0.418

Note: in the table above, the excluded group is the cohort whose community was dewormed during their third year of life or later. Standard errors are clustered at the school-cohort level; school and gender×age fixed effects are included. All cognitive outcomes are standardized (variance=1). Columns marked "w/sibs" are restricted to respondents who had at least three older siblings attend the same primary school.

Table 3: All results 2010 and 2009, saturated, individual deworming cohorts

	Outcome									
	Height		Stunting		PPVT		Raven's Matrices		Cognitive PC1	
	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs
Deworming Indicator	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Before age -1	-0.233	1.199	0.026	-0.031	0.278	0.464	0.115	1.449**	0.286	0.949*
	(0.827)	(1.380)	(0.042)	(0.072)	(0.246)	(0.512)	(0.232)	(0.63)	(0.225)	(0.514)
Age -1	0.295	1.703	-0.006	-0.063	0.252	0.537	0.275	1.314**	0.264	0.854**
	(0.677)	(1.171)	(0.034)	(0.062)	(0.203)	(0.421)	(0.199)	(0.528)	(0.184)	(0.417)
Age 0	0.326	1.719*	-0.005	-0.07	0.285*	0.483	0.226	1.172***	0.262*	0.873***
	(0.545)	(0.915)	(0.028)	(0.047)	(0.156)	(0.33)	(0.153)	(0.423)	(0.145)	(0.332)
Age 1	0.233	0.933	-0.012	-0.042	0.165	0.332	0.186	0.823**	0.155	0.458*
	(0.436)	(0.738)	(0.023)	(0.038)	(0.124)	(0.269)	(0.123)	(0.331)	(0.115)	(0.266)
Age 2	0.166	0.708	-0.01	-0.0009	0.033	-0.004	0.046	0.46*	0.034	0.407*
	(0.346)	(0.605)	(0.017)	(0.031)	(0.108)	(0.229)	(0.104)	(0.262)	(0.101)	(0.215)
Observations	13700	3057	13670	3053	2183	494	2184	493	2123	474
R^2	0.692	0.709	0.054	0.073	0.339	0.414	0.176	0.29	0.333	0.425

Note: in the table above, the excluded group is the cohort whose community was dewormed during their third year of life or later. Standard errors are clustered at the school-cohort level; school and gender×age fixed effects are included. All cognitive outcomes are standardized (variance=1). Columns marked “w/sibs” are restricted to respondents who had at least three older siblings attend the same primary school.

Table 4: All results 2010 and 2009, main effect

	Outcome									
	Height		Stunting		PPVT		Raven's Matrices		Cognitive PC1	
	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs
Deworming Indicator	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Before age 2	0.271	0.188	-0.011	-0.031	0.148*	0.307**	0.233***	0.378**	0.182**	0.288**
	(0.265)	(0.49)	(0.014)	(0.024)	(0.083)	(0.134)	(0.069)	(0.15)	(0.081)	(0.128)
Observations	13700	3057	13670	3053	2183	494	2184	493	2123	474
R^2	0.684	0.69	0.038	0.039	0.268	0.295	0.133	0.173	0.27	0.309

Note: in the table above, the excluded group is the cohort whose community was dewormed during their second year of life or later. Standard errors are clustered at the school-cohort level; gender×age and data collection year fixed effects are included. All cognitive outcomes are standardized (variance=1). Columns marked "w/sibs" are restricted to respondents who had at least three older siblings attend the same primary school.

Table 5: All results 2010 and 2009, individual deworming cohorts

	Outcome									
	Height		Stunting		PPVT		Raven's Matrices		Cognitive PC1	
	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs
Deworming Indicator	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Before age -1	0.051	-0.046	0.007	0.009	0.286**	0.328	0.235**	0.531**	0.326***	0.466**
	(0.511)	(0.854)	(0.025)	(0.042)	(0.127)	(0.205)	(0.104)	(0.221)	(0.126)	(0.214)
Age -1	0.485	0.161	-0.018	-0.011	0.197	0.337	0.342***	0.561***	0.272**	0.525**
	(0.459)	(0.786)	(0.021)	(0.042)	(0.128)	(0.211)	(0.106)	(0.21)	(0.124)	(0.215)
Age 0	0.482	0.75	-0.017	-0.034	0.217*	0.33*	0.268***	0.64***	0.244**	0.48**
	(0.434)	(0.797)	(0.022)	(0.035)	(0.115)	(0.195)	(0.1)	(0.22)	(0.113)	(0.197)
Age 1	0.375	0.035	-0.022	-0.012	0.108	0.17	0.233***	0.362**	0.148	0.249*
	(0.363)	(0.621)	(0.018)	(0.03)	(0.101)	(0.161)	(0.088)	(0.179)	(0.096)	(0.151)
Age 2	0.281	0.092	-0.018	0.023	-0.004	-0.191	0.05	0.158	0.014	0.095
	(0.327)	(0.563)	(0.014)	(0.027)	(0.098)	(0.149)	(0.091)	(0.201)	(0.093)	(0.162)
Observations	13700	3057	13670	3053	2183	494	2184	493	2123	474
R^2	0.684	0.69	0.039	0.039	0.27	0.3	0.134	0.179	0.271	0.314

Note: in the table above, the excluded group is the cohort whose community was dewormed during their third year of life or later. Standard errors are clustered at the school-cohort level; gender×age and data collection year fixed effects are included. All cognitive outcomes are standardized (variance=1). Columns marked "w/sibs" are restricted to respondents who had at least three older siblings attend the same primary school.

Table 6: All results 2010 and 2009, cognitive breakdown, main effect

	Outcome											
	Vocabulary: PPVT		Verbal fluency: Foods		Verbal fluency: Animals		Memory: Digit Span Forwards		Memory: Digit Span Backwards		Reasoning: Raven's Matrices	
	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs
Deworming Indicator	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Before age 2	0.148*	0.307**	0.101	0.055	0.155**	0.274**	0.042	0.147	0.025	0.037	0.233***	0.378**
	(0.083)	(0.134)	(0.071)	(0.147)	(0.077)	(0.137)	(0.082)	(0.146)	(0.077)	(0.156)	(0.069)	(0.15)
Observations	2183	494	2185	494	2185	494	2165	488	2134	476	2184	493
R^2	0.268	0.295	0.088	0.135	0.184	0.209	0.067	0.119	0.103	0.151	0.133	0.173

Note: in the table above, the excluded group is the cohort whose community was dewormed during their second year of life or later. Standard errors are clustered at the school-cohort level; gender×age and data collection year fixed effects are included. All cognitive outcomes are standardized (variance=1). Columns marked "w/sibs" are restricted to respondents who had at least three older siblings attend the same primary school.

Table 7: All results 2010 and 2009, cognitive breakdown, individual deworming cohorts

	Outcome											
	Vocabulary: PPVT		Verbal fluency: Foods		Verbal fluency: Animals		Memory: Digit Span Forwards		Memory: Digit Span Backwards		Reasoning: Raven's Matrices	
	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs	All	w/sibs
Deworming Indicator	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Before age -1	0.286^{**}	0.328	0.186^{*}	0.076	0.323^{***}	0.589^{**}	0.192	0.286	0.058	0.183	0.235^{**}	0.531^{**}
	(0.127)	(0.205)	(0.109)	(0.268)	(0.125)	(0.243)	(0.126)	(0.213)	(0.112)	(0.208)	(0.104)	(0.221)
Age -1	0.197	0.337	0.108	0.123	0.131	0.413^{*}	0.25^{**}	0.368^{*}	0.048	0.337	0.342^{***}	0.561^{***}
	(0.128)	(0.211)	(0.119)	(0.293)	(0.115)	(0.232)	(0.12)	(0.214)	(0.104)	(0.206)	(0.106)	(0.21)
Age 0	0.217^{*}	0.33^{*}	0.146	-0.017	0.24^{**}	0.373^{*}	0.013	0.179	0.085	0.366^{*}	0.268^{***}	0.64^{***}
	(0.115)	(0.195)	(0.099)	(0.231)	(0.102)	(0.207)	(0.105)	(0.174)	(0.104)	(0.216)	(0.1)	(0.22)
Age 1	0.108	0.17	0.077	-0.036	0.127	0.282^{*}	-0.085	0.064	0.075	0.196	0.233^{***}	0.362^{**}
	(0.101)	(0.161)	(0.08)	(0.169)	(0.093)	(0.167)	(0.09)	(0.165)	(0.095)	(0.175)	(0.088)	(0.179)
Age 2	-0.004	-0.191	-0.006	-0.165	-0.001	0.084	-0.109	-0.064	0.099	0.509^{***}	0.05	0.158
	(0.098)	(0.149)	(0.076)	(0.185)	(0.089)	(0.161)	(0.088)	(0.148)	(0.093)	(0.189)	(0.091)	(0.201)
Observations	2183	494	2185	494	2185	494	2165	488	2134	476	2184	493
R^2	0.27	0.3	0.089	0.139	0.187	0.215	0.075	0.125	0.104	0.168	0.134	0.179

Note: in the table above, the excluded group is the cohort whose community was dewormed during their third year of life or later. Standard errors are clustered at the school-cohort level; gender×age and data collection year fixed effects are included. All cognitive outcomes are standardized (variance=1). Columns marked "w/sibs" are restricted to respondents who had at least three older siblings attend the same primary school.

Table 8: Cognitive measures: Principal Components

Principal component:	(1)	(2)	(3)	(4)	(5)	(6)
Verbal Fluency: Foods	0.3650	-0.6692	0.0282	0.2175	0.5667	-0.2228
Verbal Fluency: Animals	0.4448	-0.4255	0.0033	-0.0646	-0.5401	0.5703
Digit Span Forwards	0.3788	0.2544	0.6468	-0.5451	0.2645	0.0793
Digit Span Backwards	0.3844	0.3921	0.3123	0.7682	-0.1025	-0.0192
Vocabulary: PPVT	0.4772	0.0804	-0.2700	-0.2386	-0.3825	-0.6998
Raven's Matrices	0.3872	0.3824	-0.6406	-0.0661	0.4005	0.3588
Explained variance:	0.4659	0.6196	0.7457	0.8490	0.9347	1.0000

Table 9: Cognitive measure correlations

	Fluency: Foods	Fluency: Animals	Digit Span Forwards	Digit Span Backwards	Raven's Matrices	Vocab: PPVT
Foods	1.0000					
Animals	0.5007	1.0000				
Digit Span Forwards	0.2400	0.3389	1.0000			
Digit Span Backwards	0.2323	0.3183	0.3778	1.0000		
Raven's Matrices	0.2218	0.3014	0.2742	0.3477	1.0000	
PPVT	0.3490	0.5204	0.3989	0.3899	0.5083	1.0000

Table 10: Cognitive performance (first principal component, normalized) as a function of observables

	All			Boys			Girls		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Grade	0.448***	0.38***	.	0.454***	0.405***	.	0.441***	0.348***	.
	(0.012)	(0.007)		(0.016)	(0.011)		(0.017)	(0.01)	
Age	-0.089***	.	0.264***	-0.065***	.	0.289***	-0.115***	.	0.23***
	(0.012)		(0.009)	(0.017)		(0.014)	(0.017)		(0.013)
Constant	-0.855***	-1.596***	-3.054***	-1.091***	-1.646***	-3.361***	-0.59***	-1.520***	-2.661***
	(0.104)	(0.034)	(0.108)	(0.151)	(0.048)	(0.158)	(0.143)	(0.049)	(0.148)
Observations	2181	2181	2338	1073	1073	1155	1049	1049	1124
R^2	0.56	0.548	0.26	0.579	0.573	0.283	0.538	0.517	0.228

Table 11: Cognitive performance (normalized) as a function of observables

	Outcome											
	Vocabulary: PPVT		Verbal fluency: Foods		Verbal fluency: Animals		Memory: Digit Span Forwards		Memory: Digit Span Backwards		Reasoning: Raven's Matrices	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Grade	0.367***	.	0.193***	.	0.277***	.	0.218***	.	0.225***	.	0.241***	.
	(0.008)		(0.01)		(0.009)		(0.01)		(0.01)		(0.01)	
Age	.	0.262***	.	0.144***	.	0.214***	.	0.117***	.	0.14***	.	0.174***
		(0.009)		(0.01)		(0.01)		(0.01)		(0.01)		(0.01)
Constant	-1.548***	-3.025***	-0.8***	-1.645***	-1.155***	-2.461***	-0.919***	-1.347***	-0.913***	-1.616***	-1.003***	-2.014***
	(0.035)	(0.106)	(0.046)	(0.117)	(0.042)	(0.111)	(0.045)	(0.121)	(0.046)	(0.121)	(0.044)	(0.116)
Observations	2247	2420	2249	2422	2249	2422	2224	2390	2196	2353	2248	2421
R^2	0.516	0.257	0.144	0.079	0.296	0.173	0.182	0.051	0.187	0.073	0.221	0.113