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How early nutrition and foundational cognitive skills interconnect? Evidence from two developing countries

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Abstract

We use unique data collected in Ethiopia and Peru as part of the Young Lives Study to investigate the relationship between early undernutrition and four foundational cognitive skills, the first two of which measure executive functioning: working memory, inhibitory control, long-term memory, and implicit learning. We exploit the rich longitudinal data available to control for potential confounders at the household level and for time-invariant community characteristics. We also exploit the availability of data for paired-siblings to obtain household fixed-effects estimates. Overall, we find robust evidence that stunting is negatively related with the development of executive functions, predicting reductions in working memory and inhibitory control by 12.6% and 5.8% of a standard deviation. Our results shed light on the mechanisms that explain the relationship between early nutrition and school achievement tests suggesting that good nutrition is an important determinant of children's learning capacities.

Keywords: foundational cognitive skills; early nutrition; executive functions; Ethiopia; Peru

JEL codes: I15, I25, J24

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1. Introduction

Despite considerable progress in recent years, early undernutrition is still highly prevalent in low- and middle-income countries (LMICs). An estimated 249 million children under 5 years of age are at risk of not being able to realize their developmental potential, with 170 million of them being undernourished as indicated by stunting (Lu, Black and Richter, 2016; Black, et al., 2017).[1] While the long-term consequences of early stunting on educational attainment and on school achievement tests are well-known (Glewwe et al., 2001; Alderman et al., 2006; Maluccio et al., 2009), there is scarce evidence about the specific mechanisms through which early stunting leads to poorer educational outcomes, especially in LMIC contexts. A better understanding of the mechanisms linking early nutrition with educational outcomes can be informative to design policies to improve learning. Furthermore, a major limitation of studies investigating effects of early investments in human capital on cognitive skills development is that they approximate cognitive skills using domain-specific cognitive-achievement test scores (e.g., in math, reading comprehension and vocabulary knowledge). Comparing children's scores in country settings where language and culture differ is challenging. Even when comparability is feasible, differences in test scores cannot necessarily be attributed to underlying differences in cognitive skills.

In this study, we investigate the relationship between early nutrition and the development of four foundational cognitive skills, the first two of which measure executive functioning (EF):

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[1] Stunting, measured by having height (length for infants) less than two standard deviations below the age- and sex-specific medians for well-nourished populations (e.g., WHO Multicentre Growth Reference Study Group, 2006), is the standard measure of chronic undernutrition.

inhibitory control, the capacity to control attention or behaviour and override counterproductive impulses; *working memory*, the capacity to hold in mind and manipulate information not visible in the environment; *long-term memory*, the capacity to encode, retain, and retrieve information; and, *implicit learning*, the capacity to learn without conscious awareness. We use unique cognitive data collected in Ethiopia and Peru—as part of the Young Lives Study (YLS), a longitudinal, birth-cohort study—through the administration of RACER, a tablet-based assessment tool for children and adolescents (Behrman et al., 2022, Ford et al., 2019).

Both Ethiopia and Peru face challenges related to socio-economic inequality and uneven access to educational and economic opportunities for the poor, yet they also differ substantially in their level of development and, accordingly, in the prevalence of early stunting and pre-school enrolment. The stark contrast between these two countries is useful to assess the implication of early investments in child development in different contexts.

Over the last half-century scientists have expanded theories and models that pay more attention to non-domain related skills, skills that apply across a wider array of contexts and knowledge domains– including IQ, organization, self-control, perseverance, and socio-emotional skills (Kimball, 2015; Bowles et al., 2001; Duncan et al., 2007; Heckman, 2007). Neuroscience has also shed light on the role of EF, a set of skills that are critical for controlling behaviour and ensuring that higher-level abstract goals are not supplanted by lower-level, more immediate goals (Diamond, 2013). EF is considered critical for a range of key outcomes, including school readiness (Fernald et al, 2009; Blair and Razza, 2007; Blair, 2002).[2] The existing evidence shows that EF is highly associated with early life household socio-economic status (Noble et al., 2005; Farah et al., 2006; Noble et al., 2007; Klenberg et al., 2001; Ardila et al., 2005). Stressful, challenging, or deprived conditions—such as undernutrition—may impede these skills' development and hasten their decay (Lupien et al., 2009; Shonko and Garner 2012; Nelson and Sheridan, 2011; McLaughlin and al. 2014; Sheridan and McLaughlin, 2014; Sheridan, et al., 2012; Sheridan et al., 2013). However, there is little population-based evidence on the mechanisms through which the experience of poverty, including undernutrition, lead to poorer executive functions.

Our analysis contributes to a deeper understanding of how early life events affect foundational cognitive skills and how policy interventions can help to mitigate these effects in contexts of extreme poverty, to promote lifelong-learning opportunities for all (United Nations Sustainable Development Goal #4). Such a finding is particularly important in the context of the current emphasis in research and policy on early childhood as a primary window of opportunity for intervening in child development, particularly with regard to nutrition (Victora, et al., 2008, 2010).

The paper unfolds as follows. In section 2 we describe the Young Lives' samples in Ethiopia and Peru. In section 3 we explain how each of the cognitive skills of interest is defined and measured through computer-based tasks (RACER) and explain how RACER was

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[2] Individuals with higher FCS are less likely to engage in risky behaviors related to health and crime (Cole et al., 1993; Speltz et al., 1999; McClelland et al., 2006). Recent studies to understand the skills that make workers more productive in LMIC contexts (Chile, Argentina) have added tests of FCS to better understand the skills gap among young adults (Bassi and Urzua, 2010).

administered in Peru and Ethiopia. Section 4 explains our empirical strategy. Section 5 reports our main results and robustness checks, and Section 6 concludes.

2. The Young Lives Study (YLS)

YLS is a longitudinal study that follows two cohorts of children in Ethiopia and Peru—the two study countries for this research—and in India (Andhra Pradesh and Telangana) and Vietnam: older cohorts born in 1994-1995 and younger cohorts born in 2001-2002. We focus on the Ethiopian and Peruvian younger cohort samples, tracked since ~ age 1, because these are the only samples for which the FCS data are available. The first study wave was in 2002 and was followed by four subsequent rounds in 2006 (age 5), 2009 (age 8), 2013 (age 12) and 2016 (age 15). YLS was developed as a longitudinal study of child poverty and the sampling design reflects that intent by oversampling poor households. In each country, 20 clusters (districts in Peru, *woredas* in Ethiopia) were sampled and, within each selected cluster, an area was randomly selected, and households were randomly contacted until approximately 100 eligible families were found.

In Peru, YLS staff enrolled children from 74 communities within 20 districts that were randomly selected after excluding the wealthiest 5% of districts. After districts were chosen, a census tract was randomly chosen, and then within the census tract a community or housing block was selected using random number tables. All dwellings in each block or cluster of houses were visited to identify families with children of the right ages. On completion of one block, the next available neighbouring block was visited by the fieldworker until the target number of children was found.[3] The sample represents ~95% of Peruvian children and includes urban and rural areas, the coast, highland (*altiplano*) and jungle.

In Ethiopia 20 *woredas* were purposively chosen (in states of Amhara, Oromiya, the Southern Nations, Nationalities and People's Region (SNNP), Tigray and Addis Ababa) to oversample *woredas* with food-deficit status and to capture Ethiopia's diversity across regions and a mix of geographic settings, levels of development, urban/rural balance and ethnicity. Selection of regions included identification of *woredas* in each region and peasant associations (in rural areas) or *kebeles* (the lowest level of administration in urban areas).100 young children of approximately 1 year of age were randomly selected within the chosen sites.

The younger cohorts in Ethiopia and Peru were originally composed of 1,998 and 2,052 index children, respectively. The attrition rate across all five rounds (14 years) is relatively low compared to other longitudinal studies: 5.4% in Ethiopia and 8.4% in Peru (excluding deaths). The low attrition is in part the result of the fact that migrant children and their families are followed within the countries.

In all rounds, the YLS captured various measurements of child development and other characteristics of the index children and their families, including anthropometrics (from age 1) and other individual and household characteristics. Since the third survey wave in 2009, additional data were collected on the sibling born immediately after the index child, the so-called younger sibling. In Ethiopia, when there was no immediate younger sibling present,

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[3] In 6 of the 20 districts, the population was not large enough to yield 100 children 1 year of age. In these cases, neighbouring (contiguous) districts with similar poverty rankings were selected systematically.

data for the immediate older sibling were collected. The original sample (2009) of siblings is composed of 1,001 younger siblings and 549 older siblings in Ethiopia (aged 3 to 8 and 8 to 17 years, respectively), and 861 younger siblings in Peru (aged 2 to 8 years) (see the distribution by age in months in **Figure 1**). Attrition for this sub-group in the 2013 and 2016 survey waves is very low, 7.7% and 2.2% in 2016, respectively. For the siblings' sample, anthropometric and vocabulary test data were collected since 2009.

INSERT FIGURE 1 HERE

In **Table 1** we report the means and standard deviations of selected important characteristics of the YLS Ethiopian and Peruvian samples. A number of differences emerge when comparing the two samples, partially reflecting the different sampling strategies adopted in the two countries and partially reflecting socioeconomic differences between the two countries (e.g. Ethiopia is classified by the World Bank in 2020 as a low-income country (per capita income <$1,035) and Peru as a upper-middle-income country (per capita income $4,046 TO $12,535)).[4] The Ethiopian sample is predominantly rural; in 2002, when the YLS data were collected for the first time, only 35% of the sample was living in urban areas against 69% of the Peruvian sample. Children in the Ethiopian sample are growing-up in poorer households as reflected by a lower average wealth index and the fact that their mothers, who in 95% of the cases are also the main caregivers, are significantly less-schooled on average than the mothers of the children in the Peruvian sample. Furthermore, a substantially higher proportion of index children in Ethiopia are stunted at ~ age 1 (40% versus 27% in Peru).

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[4] https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

The differences in children's nutritional status are less marked by the time of the second visit to the families, with index children ~ age 5. The changes in the gap in stunting prevalence over time between the two countries might be due partially to an underestimation of stunting prevalence in Peru ~ age 1 due to the young ages of the Peruvian children and the typical sharp downward pattern in average stunting rates in the first 24 months (see, e.g., Victora et al., 2010): Ethiopian children are on average 2 months older than children in the Peruvian sample.

INSERT TABLE 1 HERE

3. Measuring cognitive skills with RACER

In 2013-14 (Round 4) when the index children were ~12 years of age, the YLS administered a series of computer-based tasks in the Ethiopian and Peruvian samples using RACER (Rapid Assessment of Cognitive and Emotional Regulation). RACER is a touch screen computer/tablet application that uses short tasks (1 to 4 minutes each) to assess cognitive skills in children aged 6 years and older. Four cognitive skills are measured by RACER, the first two of which measure EF:

1. **Working memory** (WM), the ability to hold in mind and manipulate information that is no longer present in the environment.
2. **Inhibitory control** (IC), the ability to override counterproductive impulses and resist distraction by irrelevant information.
3. **Long-term memory** (LM), the ability to encode, retain, and retrieve new knowledge.

4. **Implicit learning** (IL), the ability to learn without conscious awareness. This skill is sometimes described as "muscle memory".

To measure these cognitive skills, RACER is composed by a set of tasks used to calculate a child's performance in challenge and baseline trials. The child´s average performance in challenge trials is the outcome of interest for our analysis—the skills measure for WM, IC, LM, and IL, respectively—, whereas the average performance in baseline trials is designed to capture other aspects not related to the measured skill, including a child's previous exposure to a tablet, motor skills, level of concentration in the task, among others—which are also captured by the challenge trials. Depending on the concept, a child´s performance is measured in terms of response time (in seconds), accuracy (distance to the correct answer, in pixels), and/or whether the child answered the trial correctly. In **Table 2** we describe the tasks included in RACER and how they relate to the cognitive skills of interest, while in **Appendix A** we report the distribution of the performance by children in challenge and baseline trials in Ethiopia and Peru. A detailed description of the trials involved in each task and how cognitive skills are measured based on this information can be found in Behrman et al. (2022).

INSERT TABLE 2 HERE

Prior to its administration, the assessment tool was pre piloted in Lima City (Peru); protocols were adjusted based on that.[5] Subsequently, enumerators were trained, and RACER and all

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[5] Although the software has on-screen instructions, it was decided that prior to the beginning of each task, the enumerator had to explain the task to the child using coloured-papers that replicated what the child was about

the other instruments of Round 4 were piloted with children aged 6 to 12 years in urban and rural areas in both countries. In total, RACER was administered to 5,759 children: in Ethiopia, 1,801 index children (aged 11 to 12 at the time) and 1,305 siblings (aged 6 to 18); in Peru, 1,902 index children (aged 11 to 12) and 784 younger siblings (aged 6 to 12). Administration time ranged between 30 and 45 minutes. Among the index children, RACER was administered to 96% of the sample available for interviews in Ethiopia and 99% in Peru. In comparison, the Peabody Picture Vocabulary Test (PPVT), a test that measures receptive vocabulary was administered to 88% of the index children in Ethiopia and 99% in Peru (Behrman et al., 2022). The distributions of the performance measures reported in **Appendix A** show that children perform better in baseline trials than on challenge trials, as expected.[6] Further analysis shows that older children and children from wealthier household and whose mothers have higher levels of education perform better in the tasks (Behrman et al., 2022).

To facilitate the interpretation of the results, we re-scale each of the measurements (average performance at challenges and baseline trials) in such a way that a higher score represents a higher level of ability. Furthermore, each of the re-scaled variables is standardized by age in years within the pooled sample. As a reference, **Table 3** reports country-sample averages of children performance in challenge and baseline trials. As can be seen, Peruvian children perform better than Ethiopian children across all challenge tasks, whereas for the baseline

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to see on the screen. After this, the enumerator was asked to watch the on-screen instructions with the child and to make sure the child understood that these instructions were the same that s/he had just explained. Other adjustments to the protocol are reported in Behrman et al. (2022).

[6] Children find it more difficult to answer accurately in the WM trials with multiple dots (compared to single-dot trials) and require more time to respond in the IC opposite-side trials (compared to same-side trials). Similarly, children need less time to respond to patterned trials in the IL task (versus un-patterned trials). For LM, the proportion of correct answers at first touch reduces in the challenge trials compared to the baseline trials.

tasks the differences are less pronounced—only in the case of LM Ethiopian children perform better than Peruvian children.

INSERT TABLE 3 HERE

4. Empirical strategy

The main objective is to test whether early undernutrition predicts child foundational cognitive skills. The specification used is as follows:

$$\mathrm{FCS}_{\mathrm{ij}} = \alpha_1 + \alpha_2 NUT_{ij} + \gamma_1 Baseline_{ij} + C_{ij}\Gamma_1 + X_{ij}\Gamma_2 + Z_{ij}\Gamma_3 + \theta_j + \varepsilon_{\mathrm{ij}} \qquad (1)$$

where FCS_{ij} is a generic variable used to denote measurements of foundational cognitive skills (IC, WM, LM and IL) of child i in cluster j at ~ age 12 in R4; NUT_{ij} is an indicator of the early nutritional status of child i in cluster j at ~ age 5; X_{ij} is a vector that includes child´s age (in months) at the time FCS_{ij} was measured, sex, the native tongue of the mother (as a proxy of ethnicity); Z_{ij} is a vector that captures measures of early life household poverty and a number of household characteristics at ~ age 1 (maternal education, wealth index[7], area of location, household size); $Baseline_{ij}$ measures child performance at the baseline tasks in the

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[7] The wealth index is a composite index combining an access-to-basic-services index (safe drinking water, adequate sanitation and electricity); a housing-quality index (main materials of walls, roof and floor satisfy basic norms of quality); and, an index of consumer durables (household owns radio, television, bicycle, motorbike, automobile, landline phone, mobile phone, refrigerator, stove, blender, iron, record player, computer or laptop) (Briones, 2017). Households are categorised into quintiles based on their wealth index, with the households with lowest wealth belonging to the bottom quintile, and those with the highest wealth belonging to the top quintile.

RACER application–this controls for other domain-general skills and capabilities different from the skill being tested (e.g., the fact that some children had never seen a tablet before); C_{ij} is a vector that controls the day of the week (weekend or not) and the time of the day (morning or afternoon) when the tasks were administered; θ_j is a cluster fixed effect to control for unobserved (time-invariant) characteristics common to all children in cluster j at ~ age 1, and ε_{ij} is a measurement error. To increase statistical power and allow for more variation in the skills and nutritional variables we use data from index children and younger siblings in Peru and Ethiopia, as well as older siblings in Ethiopia. Equation (1) is estimated for the pooled sample of Ethiopia and Peru, and separately by country.

The coefficient of interest is α_2. The early nutritional status of the child, NUT_i, is proxied by stunting. Stunting is a measure of chronic undernutrition that is widely used in the nutritional literature and in development economics (see, for instance, Alderman, 2000).[8] A child is identified as stunted if his/her height-for-age Z-score (HAZ) is two standard deviations or more below the WHO age-gender specific medians. Height-for-age is standardized according to age- and gender-specific child growth standards provided by the World Health Organization (WHO Multicentre Growth Reference Study Group, 2006) which are universally comparable. The resulting HAZ is an indicator of cumulative deficient growth.

Our main specification might still be afflicted by omitted variable bias. A key concern is that parents that have a higher preference for child quality might invest more in the health and education of their children, thus explaining differences in nutritional status and in the

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[8] Height-for-age is less sensitive than weight-for-age and weight-for-height to temporary shocks due to morbidity and illnesses or seasonal variations in food availabilities.

cognitive skills measured by RACER. To account for this possibility, we implement a household fixed-effects estimation, as follows:

$$\mathrm{FCS_{ik}} = \alpha_1 + \alpha_2 NUT_{ik} + \gamma_1 Baseline_{ik} + C_{ik}\Gamma_1 + X_{ik}\Gamma_2 + Z_{ik}\Gamma_3 + \theta_k + \mathrm{\varepsilon_{ik}} \qquad (2)$$

where $\mathrm{FCS_{ik}}$ represents the outcome of interest of child i from household k, and θ_k represents unobserved heterogeneity that is common across siblings—including parental preferences for child quality. By construction, this specification controls for differences between siblings in sex, age, in performance in the baseline tasks, time of administration (weekday or weekend; time during the day), and in time-varying early-life household characteristics (wealth index, area of location, and household size)—from the control variables included in equation (1), only maternal education and maternal native tongue were time invariant.

Approximating stunting at the age of 5

We focus on stunting measured at ~5 years of age, which marks the end of the pre-school period. However, not all children in the samples have their HAZ observed at that age. The index children and younger siblings are approximately 5 years of age in rounds 2 and 3 (respectively), albeit with dispersion around the mean (4 to 5 years of age for the index children, 3 to 7 years for the younger siblings). Furthermore, for the older siblings the earliest measurement of HAZ is observed at ages 9 to 14. As shown in **Figure 2**, in both country samples HAZ improves as children age. Therefore, observed HAZ at other ages might not be the best approximation for children’s nutritional status at age 5.

INSERT FIGURE 2 HERE

To deal with this, we apply two different strategies depending on whether observed HAZ is measured close to the age of 5 (index children and younger siblings) or not (older siblings). If HAZ is measured at approximately 5 years of age, we adjust a child's HAZ taking into account average differences in HAZ observed by age in months in each country sample, thus purging differences in HAZ that are likely to be purely driven by the age at which the child is observed. Conversely, if no HAZ measures at the age of 5 are available, we estimate a model that assumes that two measurements of a child´s HAZ are observed, one at around the age of 60 months (5 years), and one at a later age. This model is calibrated using data from the index children and younger siblings for which this assumption holds, and the predicted coefficients are used to extrapolate the HAZ that older siblings might have had if they had been observed at the age of 5 years (60 months). More details about the procedure followed in each case are reported in **Appendix B**.

Figure 3 reports the observed and adjusted HAZ of the pooled sample, separately for each country sample. For the Ethiopian sample, both distributions appear to be similar and lead to similar stunting levels (32% and 33% in the observed and adjusted scenarios, respectively), whereas in the Peruvian sample the adjusted HAZ distribution is shifted to the left, which leads to a larger prevalence of stunted children (40% compared to 33% in the observed distribution). This is expected since this is the sample where most recovery from stunting was observed after the age of 5 in the countries where Young Lives collects data (Lundeen et al., 2013). From here onwards, we focus on adjusted HAZ.

INSERT FIGURE 3 HERE

5. Results

Before looking at the main results, in **Table 4**, we report the associations between nutrition and each of the cognitive measurements, for the pooled sample and separately by country sample. Results come from an OLS model that only controls for whether the child is the index child, a younger sibling, or an older sibling. All the coefficients have the expected positive signs and are statistically significant. Focusing on the pooled sample, stunting is associated with subsequent reductions in WM, IC, LM, and IL by 21%, 16.7%, 9.8%, and 11.9% of a standard deviation, respectively (Panel A). As a reference, the analogous associations using HAZ as nutritional indicator are reported in Panel B. HAZ is associated with subsequent improvements in WM, IC, LM, and IL, by 9.8%, 8.9%, 5.7%, and 6.4% of a standard deviation, respectively. In both cases, the magnitude of the coefficients for WM and IC are larger for the Peruvian sample (in absolute values), and the differences are statistically significant.

INSERT TABLE 4 HERE

In **Table 5**, Panel A, we report results of estimating equation (1) for Ethiopia and Peru. This model controls for child and household characteristics, community at age~1 fixed effects, and performance in the baseline tasks (which captures abilities required to perform well using the tablet). Full versions of the regressions for Ethiopia and Peru are reported in **Table C1** in

Appendix C.[9] Focusing on the pooled sample, the adjusted R-squared ranges between 32% and 39% for the EF measurements, has its lowest value (18%) for LM, and its highest value (58%) for IL. In the case of LM, the low value of the adjusted R-squared (in relative terms) is driven by the Peruvian sample (8%, compared to 27% in Ethiopia). Results suggests that nutrition has a role in explaining EF. Stunting leads to a reduction of WM and IC by 7.9% and 4.5% of a standard deviation in the pooled sample, respectively. The point estimates are larger for the Peruvian sample (in absolute values), but the differences are not statistically significant. In relation to the non-EF measurements, no evidence is found for the pooled sample—in fact, the point estimate for IL is close to zero. In the country-specific estimates, only for LM a relationship is found for Ethiopia (stunting leads to a reduction in this skill by 12.6%).

INSERT TABLE 5 HERE

In Panel B, we present household fixed-effects estimates, as in equation (2). This is our preferred specification, as it purges any remaining heterogeneity in the cognitive skills measured by RACER that could be explained by household unobserved characteristics that simultaneously determine investments in nutrition and skills. Results from this specification confirm that early stunting is associated with EF. In the pooled sample, stunting leads to a reduction in WM and IL by 12.6% and 5.8% of a standard deviation, respectively. Similar

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[9] The key covariate across all measurements of cognitive skills is the child performance in the baseline trials. These are the variables with the highest contribution to the adjusted R-squared. Looking at household characteristics, which capture aspects related to the socio-economic status of the family, we find that maternal education—in particular, having a mother with tertiary education—predicts better performance in the WM and LTM tasks in the Peruvian sample, but not in the Ethiopian sample. Belonging to the upper quintiles of wealth predicts a better performance in LTM, IC in Ethiopia, and LTM and IL in Peru. Maternal native tongue also explains some heterogeneity in the results, for IL in Peru, and for WM, LTM, and IL in Ethiopia.

point estimates are obtained for Ethiopia and Peru for WM (between '-10%' and '-13%') and IC (between '-6%' and '-5%'), which are statistically significant except for IC for Peru. In fact, the point estimates obtained with the household fixed-effects strategy for stunting tend to be larger (in absolute value) compared to those obtained by OLS. As before, no significant result is found for LM or IL in the pooled sample, and the coefficient linking stunting to LM is no longer statistically significant.

A potential concern of this specification is that it might still be afflicted by bias due to differential investments across siblings. Although this possibility is limited in this case because the specification controls for sibling-differences in early life household wealth—this captures, for instance, if the household socio-economic status has improved over time, benefiting the younger sibling—, there might be differential investments within the household associated with the birth order of the child. For instance, the index child—who is by construction older than the other sibling for all of the Peruvian sample and for the majority of the Ethiopian sample— might have benefited for being born first (Behrman, 1988). To partially alleviate this concern, in **Table C2** (Appendix), we report results from an alternative household fixed-effects specification that controls for birth order (whether the index child was the first-born in the household) and birth-sex order. Our conclusions remain unchanged.

To understand if our conclusions are sensitive to the adjustment made to stunting, in **Table C3** (Appendix) results are reported using the child's stunting observation closest to the age of five measured in the Young Lives Study, without any further adjustment. When doing this, our conclusions about the role of stunting on EF remain unchanged—for the pooled sample, there is virtually no change in the magnitude and statistical significance of the coefficients.

Our preferred specification controls for child performance in the baseline task. Although the baseline is not a measure of cognitive skills *per se*, in practice it is likely to capture a child's general abilities. For this reason, we explore how results change if $Baseline_i$ is excluded from the main specification, and, also, estimate an auxiliary model in which $Baseline_i$ is the dependent variable. In **Table C4**, we report results without controlling for baseline performance. When doing this, the point estimates are larger (in absolute values) in the pooled sample and in the Ethiopian sample. These results suggest that performance in the baseline trials might be affected by early nutritional status. This hypothesis is formally tested in **Table C5**, where the child performance in the baseline tasks is used as dependent variable. Considering the preferred specification (with household fixed effects), results suggest that early stunting has an impact on the general abilities required to answer RACER trials related to WM and IC in the Ethiopian sample.

To assess the sensitivity of our main results to the use of stunting as a nutritional indicator, in **Table C6**, alternative results are presented using HAZ instead of stunting as the independent variable of interest. For the pooled OLS model (Panel A), the same patterns are observed: an increase in HAZ by one standard deviation is associated with subsequent increases in WM and IC by 4.2% and 2.9% of a standard deviation, respectively. In this case, the standardized coefficient for LM is statistically significant in the pooled sample (2.3%). As before, the result is driven by the Ethiopian sample (4.9% of a standard deviation). Considering the preferred specification (household fixed-effects estimates, reported in Panel B), as before the results linking nutritional status to LM becomes statistically insignificant in this case. Furthermore, using HAZ the results linking early nutrition to IC also become statistically insignificant, only the coefficients linking early nutrition to WM remains significant in this case. Given that not all the variation in early HAZ can be necessarily attributed to differences in early life nutritional investments—e.g., differences in HAZ for those children that are above the median WHO references for their age might not indicate better nutritional status—these additional results need to be interpreted with caution.

Heterogenous effects

We expect that the impact of early nutrition on cognitive skills might decline as children age, and other factors become more important—e.g., school investments. To formally test this hypothesis, in **Table 6**, Panel A, we interact age in months with all the variables in the model, and report specifically the coefficients linked to stunting. For the EF measurements, we find evidence supporting the hypothesis that the association of stunting with skills declines with age for WM (pooled sample). The result is driven by the Peruvian sample. For the non-EF measurements, we find that the association of stunting with IL declines with age (pooled sample), and the result is driven by the Ethiopian sample.

In Panel B, we test whether the associations of FCS with stunting differ by gender by including interactions between gender and all the variables in the model. In this case we find no evidence pointing to differential effects by gender in the pooled sample.

INSERT TABLE 6 HERE

6. Conclusions and implications for policy

Most of the existing literature on the determinants of early skills comes from experimental studies in developed countries with typically very small samples. This paper investigates the potential associations of early undernutrition (proxied by height-for-age and stunting at the age of five) on a set of foundational cognitive skills in two large samples of children in Ethiopia and Peru. Overall, we found that early nutritional status is associated with the development of executive functions—working memory and inhibitory control. This conclusion is robust to the inclusion of household fixed effects, using stunting as a nutritional indicator. Considering this specification, the point estimates for Ethiopia and Peru are not statistically different. Our findings contribute to previous studies that found a linkage between early nutrition and schooling achievement (Glewwe et al., 2001; Alderman et al., 2006; Maluccio et al., 2009), by showing one way in which this relationship is mediated.

In contrast, no evidence of a linkage between early nutrition and implicit learning is found. Some evidence about the importance of nutritional investments for the development of long-term memory is found in the Ethiopian sample, however these results are not very robust. The absence of evidence of an association of nutrition with implicit learning is not necessarily surprising, given that this is very basic cognitive skills that is only affected under very extreme circumstances. A priori, it is expected to vary less across population subgroups than our other measures (Hamoudi and Sheridan, 2015).

We identify two areas for which our results are of interest for policy makers. First, given that executive functioning is a well-known predictor of educational attainment, our results provide another reason to justify the promotion of investments in early nutrition in developing countries, as part of the strategies implemented by countries to promote equity in learning outcomes, one of the Sustainable Development Goals. Second, in the past it has been difficult and expensive to measure foundational cognitive skills in population studies. Using assessment tools such as RACER is relatively inexpensive and could be used to monitor progress towards these goals over time.

Tables and Figures

Figure 1. Age distribution by country samples

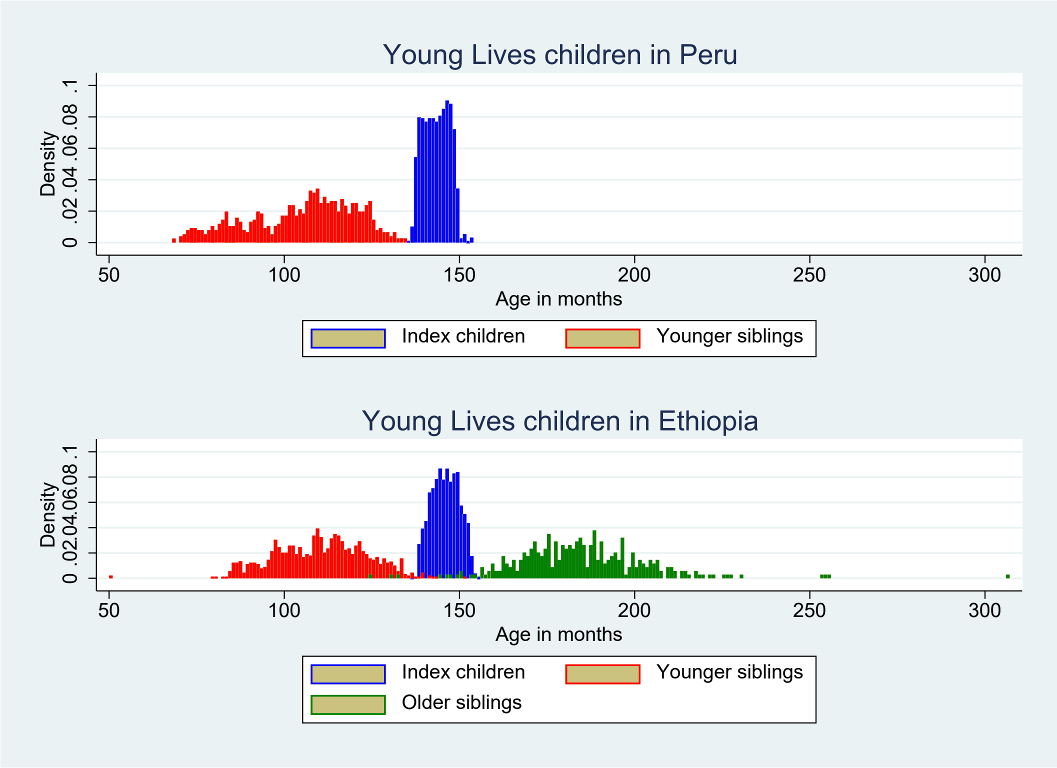

Figure 2. Average height-for-age Z-score (HAZ) by age in semesters

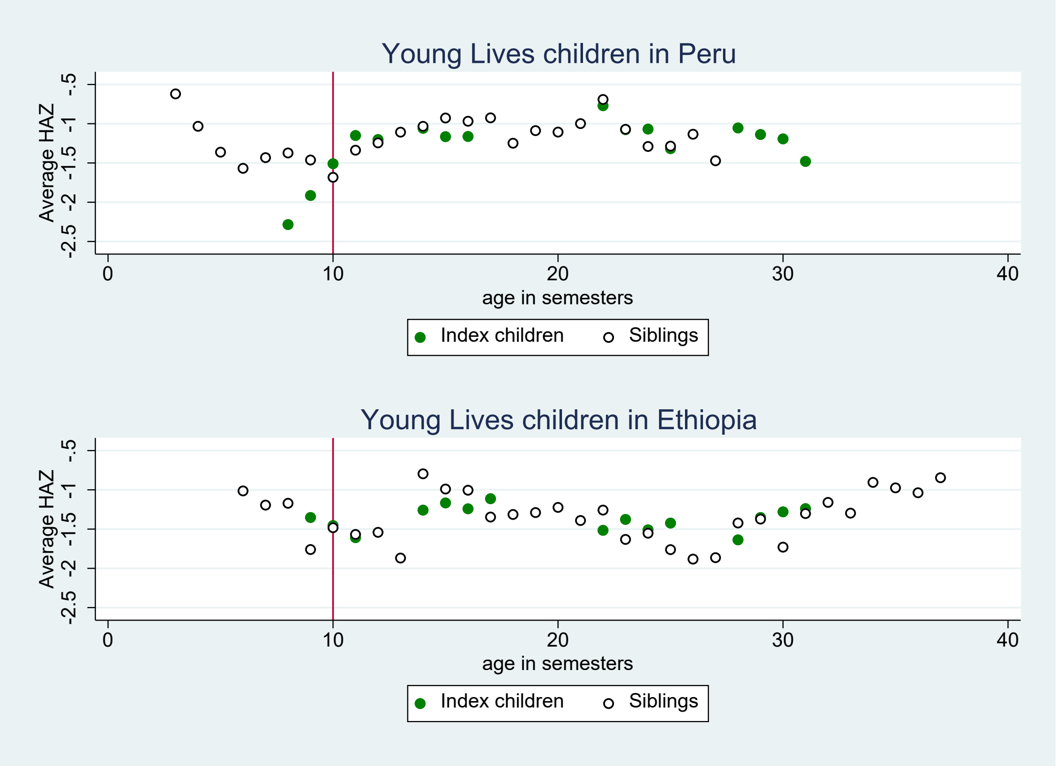

Figure 3. Height-for-age Z-score (HAZ) in the Young Lives samples in Ethiopia and Peru: observed versus adjusted

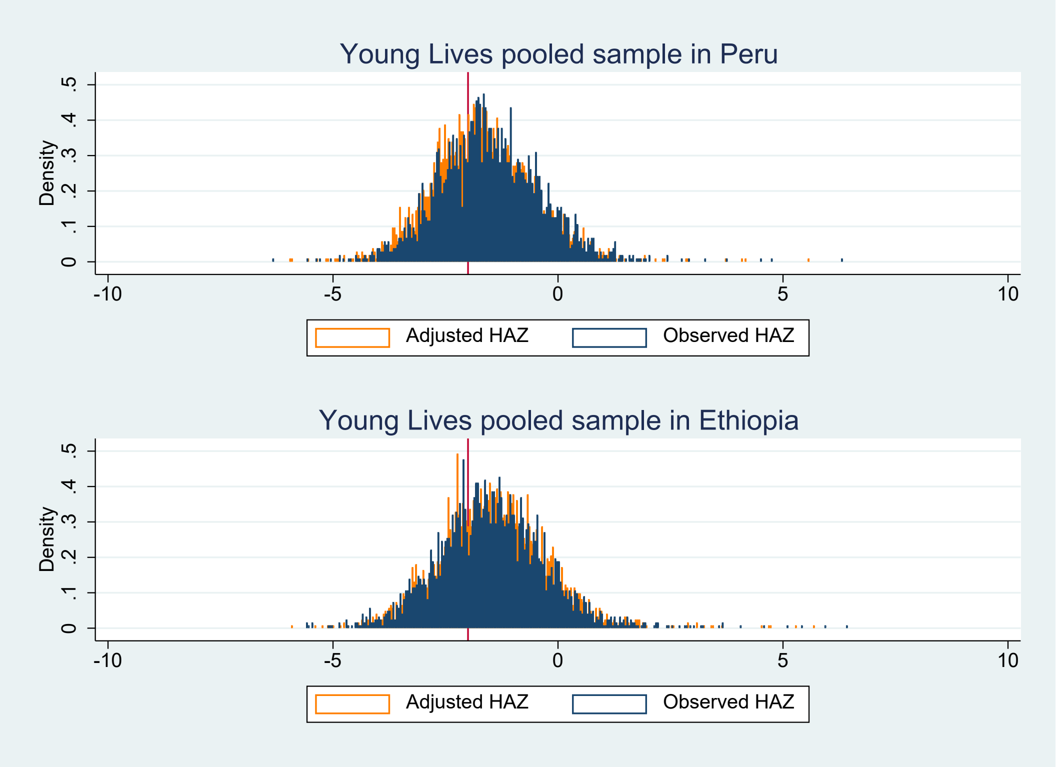

Table 1. Descriptive statistics of the Young Lives sample in Ethiopia and Peru

	Ethiopia		**Peru**	
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**
Maternal education, in %				
ET: No education; PE: Less than primary	50.4	-	35.8	-
ET: Lower primary (Gr 1-4); PE: Complete primary	23.6	-	29.0	-
ET: Upper primary (Gr 5-8); PE: Complete secondary	16.2	-	20.9	-
ET: More than Grade 8; PE: Higher education	9.8	-	14.3	-
Urban area, in % (Round 1, 2002)	34.8	47.7	68.9	46.3
Wealth index (Round 1, 2002)	0.225	0.190	0.431	0.237
Nutritional status (Index Children)				
Stunting, in % (Round 1, 2002)	40.0	49.0	27.2	44.5
Height-for-age Z-score (Round 1, 2002)	-1.44	1.725	-1.26	1.249
Stunting, in % (Round 2)	30.3	45.6	32.4	46.8
Height-for-age Z-score (Round 1, 2002)	-1.43	1.093	-1.51	1.079
Number of observations	1,787		1,681	

Note: Maternal education is defined differently in the two countries as specified in the table. The sample corresponds to the balanced sample of index children observed in rounds 1, 2 and 4, with non-missing information on the selected variables.

Table 2: Description of cognitive skills measured by RACER tasks

Cognitive skill (1)	Order of task (3)	Cognitive Task (4)	Preferred outcome measure (5)	Baseline performance (6)	Challenge performance (7)
Long-term memory	Task 1 & 5	Paired Associate Learning Task "Memory Game 1" Task 1, two presentations of the (same) six pairs "Memory Game 2" Task 5 (same as Task 1, excluding tutorial & practice test)	Correct answer is provided at first touch	First time the six pairs are presented (trials) Number of trials: 6	Second, third and fourth time the (same) six pairs are presented (trials) Number of trials: 18
Inhibitory Control	Task 2	Simon Task "Sides Game"	Equally weighted average of response time, and Euclidean distance (log scale)	Same-side trials Number of trials: 7	Opposite-side trials Number of trials: 14
Working Memory	Task 3	Spatial Delayed-Match-to-Sample Task "Finding the Dots"	Euclidean distance (log scale)	Short-delay, single-dot trials Number of trials: 30	Long-delay, multiple-dots trials Number of trials: 30
Implicit Learning	Task 4	Adapted Serial Reaction Time Task "Catching Chickens/ Chasing dots"	Response time	Non-patterned trials Number of trials: 70	Patterned trials Number of trials: 105

Source: adapted from Behrman et al. (2022).

Table 3. Average performance at challenge and baseline tasks in Peru and Ethiopia

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A (challenge task)					
Peru	Mean	0.17	0.12	0.13	0.09
	Std. Dev.	(0.981)	(0.776)	(0.996)	(1.106)
Ethiopia	Mean	-0.15	-0.10	-0.10	-0.08
	Std. Dev.	(0.989)	(0.636)	(0.986)	(0.886)
	T-test (p-value)	*0.000*	*0.000*	*0.000*	*0.000*
Panel B (baseline task)					
Peru	Mean	0.02	0.20	-0.13	0.03
	Std. Dev.	(0.976)	(0.710)	(0.916)	(1.045)
Ethiopia	Mean	-0.02	-0.17	0.11	-0.02
	Std. Dev.	(1.006)	(0.602)	(1.056)	(0.952)
	T-test (p-value)	*0.088*	*0.000*	*0.000*	*0.061*
Sample size					
Peru		2,556	2,561	2,561	2,554
Ethiopia		3,038	3,038	3,038	3,038

Table 4. Correlation between nutritional status and foundational cognitive skills (bivariate OLS)

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A (nutritional indicator: stunting)					
-					
Pooled sample	Coef.	-0.210***	-0.167***	-0.098**	-0.119***
	Std. Error	(0.032)	(0.025)	(0.039)	(0.035)
	Adjusted R2	*0.010*	*0.012*	*0.002*	*0.003*
Peru	Coef.	-0.314***	-0.236***	-0.100**	-0.132**
	Std. Error	(0.036)	(0.034)	(0.042)	(0.047)
	Adjusted R2	*0.025*	*0.022*	*0.002*	*0.003*
Ethiopia	Coef.	-0.163***	-0.148***	-0.140**	-0.140***
	Std. Error	(0.046)	(0.030)	(0.065)	(0.048)
	Adjusted R2	*0.008*	*0.016*	*0.007*	*0.007*
Difference	*T-test (p-value)*	*0.013*	*0.053*	*0.622*	*0.915*
Panel B (nutritional indicator: HAZ)					
-					
Pooled sample	Coef.	0.098***	0.089***	0.057***	0.064***
	Std. Error	(0.016)	(0.014)	(0.018)	(0.019)
	Adjusted R2	*0.013*	*0.021*	*0.004*	*0.005*
Peru	Coef.	0.161***	0.139***	0.070***	0.069**
	Std. Error	(0.023)	(0.021)	(0.017)	(0.029)
	Adjusted R2	*0.034*	*0.040*	*0.005*	*0.004*
Ethiopia	Coef.	0.079***	0.075***	0.070**	0.077***
	Std. Error	(0.021)	(0.014)	(0.029)	(0.024)
	Adjusted R2	*0.011*	*0.024*	*0.009*	*0.012*
Difference	*T-test (p-value)*	*0.010*	*0.015*	*0.989*	*0.847*
Sample size					
Peru		2,556	2,561	2,561	2,553
Ethiopia		3,038	3,038	3,038	3,037

Note: All coefficients are standardized. Each coefficient comes from a different bivariate model, controlling for whether the child is an index children, younger sibling, or older siblings. Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

Table 5. Main results: Impact of nutritional status on foundational cognitive skills

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A: multivariate OLS					
-					
Pooled sample	Coef.	-0.079***	-0.045**	-0.036	0.009
	Std. Error	(0.023)	(0.018)	(0.030)	(0.019)
	Adjusted R2	*0.315*	*0.388*	*0.184*	*0.572*
Peru	Coef.	-0.102***	-0.051*	0.052	0.001
	Std. Error	(0.026)	(0.029)	(0.044)	(0.035)
	Adjusted R2	*0.310*	*0.390*	*0.080*	*0.517*
Ethiopia	Coef.	-0.051	-0.038	-0.126***	0.011
	Std. Error	(0.038)	(0.022)	(0.037)	(0.017)
	Adjusted R2	*0.289*	*0.353*	*0.268*	*0.638*
Panel B: household fixed effects					
-					
Pooled sample	Coef.	-0.126***	-0.058**	0.014	0.006
	Std. Error	(0.044)	(0.030)	(0.048)	(0.036)
Peru	Coef.	-0.130**	-0.051	0.023	-0.011
	Std. Error	(0.065)	(0.056)	(0.086)	(0.067)
Ethiopia	Coef.	-0.103*	-0.063*	-0.034	-0.000
	Std. Error	(0.059)	(0.034)	(0.055)	(0.041)
Sample size					
Peru		2,497	2,501	2,501	2,491
Ethiopia		2,901	2,901	2,901	2,900

Note: All coefficients are standardized. Each coefficient comes from a different estimation linking stunting to a given FCS. Results from panel A correspond to equation (1) (pooled OLS). Controls included: child´s age (in months) and sex; native tongue of the mother and maternal education; wealth index (in quintiles) at age 1, area of location at age 1, household size at age 1; community fixed effects at age 1 (specific to the index child); performance in the baseline tasks, whether the task was administered during the weekend, and the time of the day when the tasks were administered. Results from panel B correspond to a household fixed effects specification (equation (2)). Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

Table 6. Main results: Impact of nutritional status on cognitive skills, heterogenous effects by age and sex

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A (nutritional indicator interacted with age)					
Pooled sample	Coef. (Stunting)	-0.469***	-0.084	0.128	-0.211*
	Std. Error	(0.156)	(0.116)	(0.136)	(0.114)
	Coef. (Stunting*AGE)	0.003**	0.000	-0.001	0.002*
	Std. Error	(0.001)	(0.001)	(0.001)	(0.001)
Peru	Coef. (Stunting)	-0.643**	-0.324	0.058	-0.176
	Std. Error	(0.267)	(0.212)	(0.226)	(0.187)
	Coef. (Stunting*AGE)	0.004*	0.002	-0.000	0.001
	Std. Error	(0.002)	(0.002)	(0.002)	(0.001)
Ethiopia	Coef. (Stunting)	-0.338	0.086	0.062	-0.266
	Std. Error	(0.197)	(0.132)	(0.166)	(0.156)
	Coef. (Stunting*AGE)	0.002	-0.001	-0.001	0.002*
	Std. Error	(0.001)	(0.001)	(0.001)	(0.001)
Panel B (nutritional indicator interacted with sex)					
Pooled sample	Coef. (Stunting)	-0.068**	-0.027	-0.022	0.025
	Std. Error	(0.029)	(0.023)	(0.044)	(0.021)
	Coef. (Stunting*AGE)	-0.030	-0.041	-0.050	-0.037
	Std. Error	(0.054)	(0.032)	(0.058)	(0.036)
Peru	Coef. (Stunting)	-0.094**	-0.054	0.037	-0.006
	Std. Error	(0.035)	(0.039)	(0.070)	(0.038)
	Coef. (Stunting*AGE)	-0.103*	-0.029	-0.123	-0.022
	Std. Error	(0.058)	(0.054)	(0.086)	(0.050)
Ethiopia	Coef. (Stunting)	-0.085*	-0.026	-0.111*	0.015
	Std. Error	(0.048)	(0.027)	(0.059)	(0.021)
	Coef. (Stunting*AGE)	0.056	-0.036	-0.061	-0.036
	Std. Error	(0.088)	(0.040)	(0.083)	(0.040)
Sample size					
Peru		2497	2501	2501	2491
Ethiopia		2901	2900	3038	3038

Note: All coefficients are standardized. Same control variables as in equation (1). Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

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APPENDIX A

Figure A1. Performance indicator distribution on trials related to long-term memory: percentages of correct answers at the first touch, Ethiopia and Peru index children

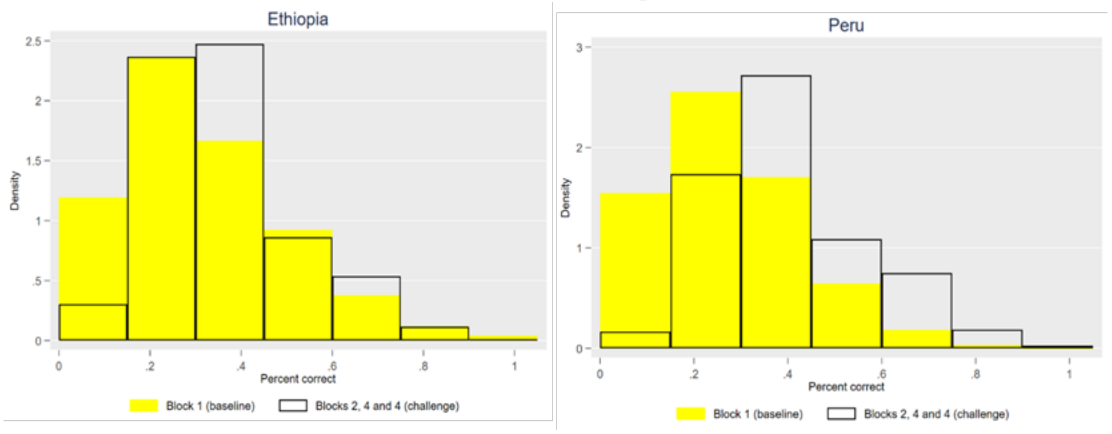


Figure A2. Performance indicator distributions on trials related to inhibitory control: response time (in seconds), Ethiopia and Peru index children

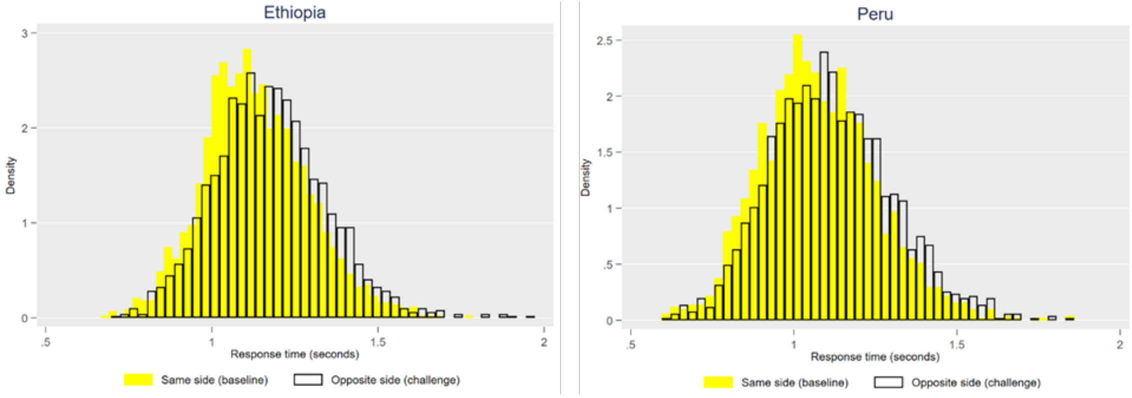


Figure A3. Performance indicator distributions on trials related to working memory: Euclidean distance from touch to correct location (log scale), Ethiopia and Peru index children

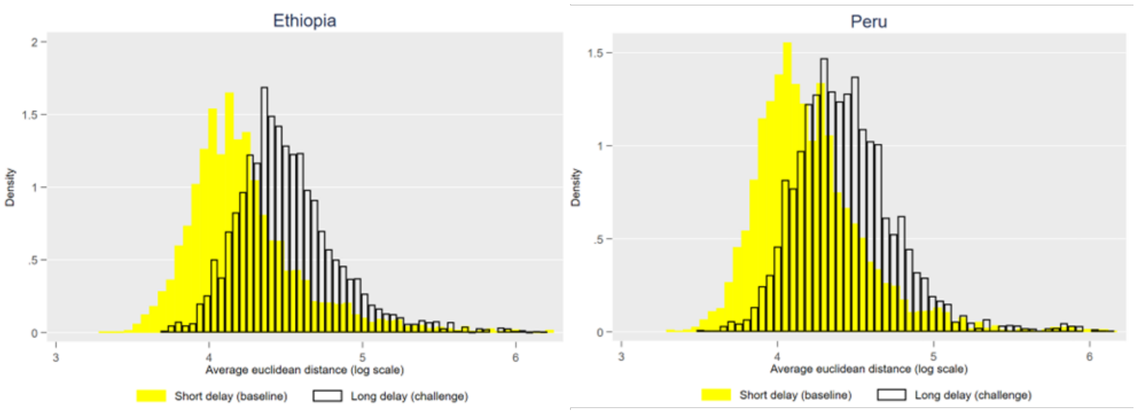


Figure A4. Performance indicator distributions on trials related to working memory: Euclidean distance from touch to correct location (log scale), Ethiopia and Peru index children

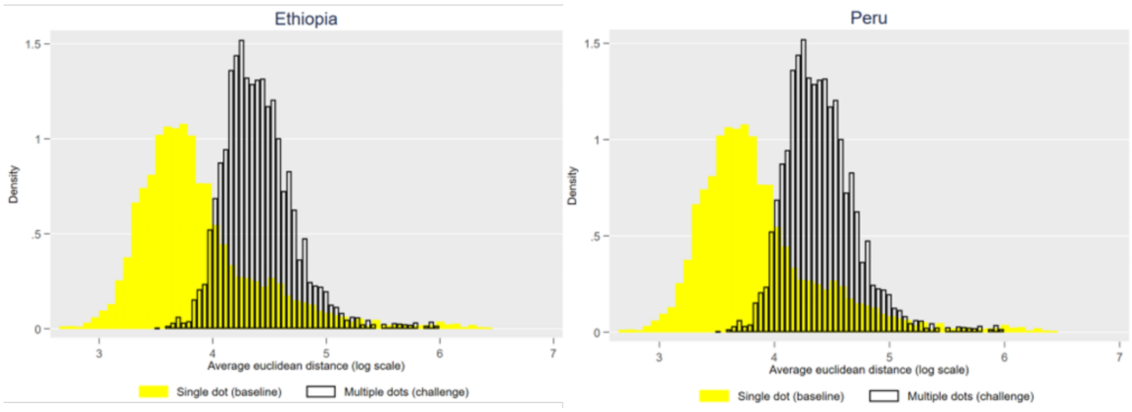
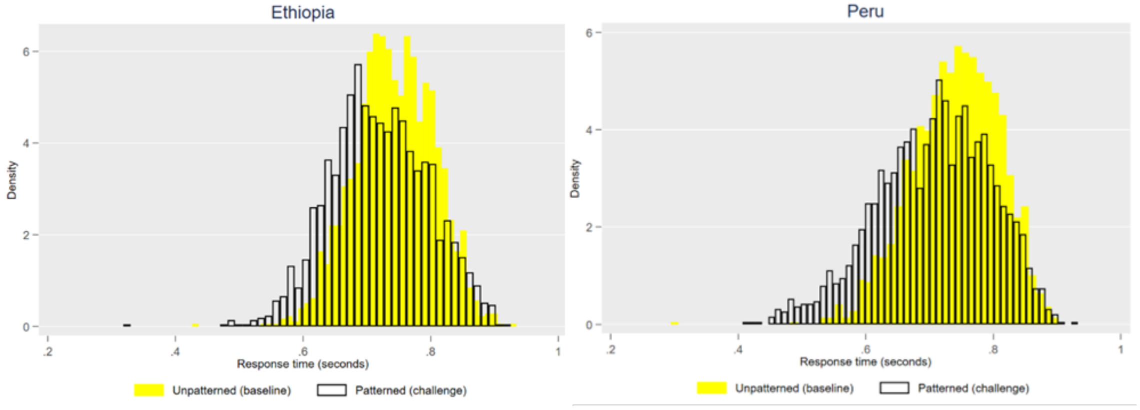


Figure A5. Performance indicator distributions on trials related to implicit learning: Reaction time (in seconds), Ethiopia and Peru index children



APPENDIX B

Adjustment of height-for-age around the age of 5 years

This note explains how HAZ at age 60 months (five years) is predicted for YLS children in the Peruvian and Ethiopian samples, using data from rounds 2, 3 and 4. We use two different prediction models, one for the older siblings and one for the group of index children and younger siblings.

1. For the older siblings, we estimate a model that assumes that two measurements of height-for-age can be observed, one at around the age of 60 months, and one at a later age. This model is calibrated using data from the index children and younger siblings, and the predicted coefficients are used to extrapolate the prediction of the HAZ that older siblings would have had if they had been observed at the age of 60 months.

2. For the younger siblings and index children, HAZ is observed closer to the age of 60 months. For this reason in this case we simply adjust HAZ taking account average differences in HAZ observed by age in months in each country.

Data

Table 1 shows the mean age and age range for each group of children in each round. Information centered around the age of 60 months is observed for the Index Children in Round 2 and for Younger Siblings in Round 3. In contrast, for the Older Siblings there is no information available close to that age. The earliest information for the Older Siblings was obtained in Round 3, when average age was 136 months, with a range between 110 and 165 months. This range partially overlaps with the Index Children as observed in Round 4 (ages between 139 and 152 months) and the Younger Siblings in Round 4 (ages between 87 and 131).

Table B1

Cohort	n	Mean	Median	Min	Max	p.5	p.95
Ethiopia							
Index children							
Round 2	1,801	61.8	62	52	75	56	68
Round 3	1,797	97.5	98	88	138	91	104
Round 4	1,801	145.5	146	136	156	139	152
Younger siblings							
Round 3	883	61.6	62	0	137	39	83
Round 4	883	110.1	110	50	187	87	131
Older siblings							
Round 3	343	135.7	134	77	258	110	165
Round 4	343	184.2	183	124	307	159	213
Peru							
Index children							
Round 2	1,848	63.5	64	53	75	55	71

Round 3	1,851	94.9	95	85	106	89	100
Round 4	1,852	142.9	143	135	154	137	148
Younger siblings							
Round 3	755	56.4	59	21	87	24	77
Round 4	755	104.5	107	68	135	71	131

Note: data from Round 1 is not used because then index children aged 6 to 18 months, which does not overlap with the age of the younger siblings in round 3.

Older siblings in Ethiopia

The age structure presented above suggests that to predict HAZ at 60 months for the Older Siblings, the following steps can be taken:

1. Use data from the Index Children and Younger Siblings.
2. Estimate a model linking HAZ centered at 60 months as a function of HAZ observed at a later age, and other child and household characteristics.
3. Use these coefficients to predict HAZ at 60 months for the Older Siblings (out of sample prediction).

To further increase precision, it is important to recognize that in some households, both Index Children and Younger Siblings are observed. For this reason, to predict HAZ, we consider the following model:

$$haz_{i,r} = a_1 age_{i,r} + a_2 age_{i,r}^2 + a_3 hazref_{i,r*} + a_4 ageref_{i,r*} + a_5 ageref_{i,r*}^2 + a_6 Ind_i + a_7 HH_i + a_8 hazref_{j,r*} + a_9 ageref_{j,r*} + a_{10} ageref_{j,r*}^2 + u_i \quad (1)$$

where $haz_{i,r}$ is the HAZ of child i observed in round r; $age_{i,r}$ is the age of the child i in round r, expressed in months; $hazref_{i,r*}$corresponds to another measure for HAZ for child i observed in round r* such that r*>r (as defined below); $ageref_{i,r*}$ is the age at which this alternative measure of HAZ is observed; Ind_i is a vector that contains sex and other individual characteristics of child i; $hazref_{j,r*}$, is the HAZ of sibling j observed in round r; ; HH_i includes household characteristics common to both siblings; and u_i is measurement error. In practice, Model (1) is expanded by interacting all coefficients with age_i and age_i^2, denominated as model (1'), and this is the model of interest to us.

We estimate model (1') for the following combinations of ($haz_{i,r}, hazref_{i,r*}, hazref_{j,r*}$):

Cohort	$haz_{i,r}$	$hazref_{i,r*}$	$hazref_{j,r*}$
(i=index; j=younger sib)	r=2	r=4	r=4
(i= younger sib; j= index)	r=3	r=4	r=4

Once the coefficients of this model are obtained, these are used to predict HAZ at age 60 months for the Older Siblings. For this purpose, we consider the following steps:

1. $age_{i,r}$ and $age_{i,r}^2$ are set to 60 and 3600.
2. For Older Siblings, child i defined as the Older Sibling, and j as the Index Child.
3. For Older Siblings, $hazref_{i,r*}$ refers to HAZ measured in round 3.

The resulting model has an adjusted R squared of 0.50. A true assessment of the model can only be obtained for a group of 157 children that aged exactly 60 months when observed. This is reported in **Figure B1.i**. Finally, the predicted value of HAZ at the age of 60 months obtained for the older siblings—which is the 'out of sample' group-- is reported in **Figure B1.ii**. Following model (1'), through LASSO it is possible to identify the set of coefficients that minimizes prediction error. The model selected by LASSO is the one finally used.

Figure B1


i.
ii.

Index children and younger siblings

For the index children and younger siblings, in theory it is possible to use the model reported above, however in doing so we would lose useful information about the HAZ observation that is already close to the age of 60 months. Therefore, in this case we use an approach inspired by Crookston et al. (2013, Am J Clin Nut. r). Consider the following linear in parameters model: $haz_i = a_0 + a_1 age_i + a_2 age_i^2 + \cdots + a_p age_i^p + u_i$, where haz_i is HAZ, age_i is age in months, and p is the degree of the polynomial. Once the coefficients are estimated, we have that,

$$haz_i = \widehat{a_0} + \widehat{a_1} age_i + \widehat{a_2} age_i^2 + \cdots + \widehat{a_p} age_i^p + \widehat{u_\imath} \qquad \text{(a)}$$

suppose the child is more than 60 months of age at the time he/she is observed. Assuming that HAZ is only a function of age, then haz_i^* predicted can be obtained as:

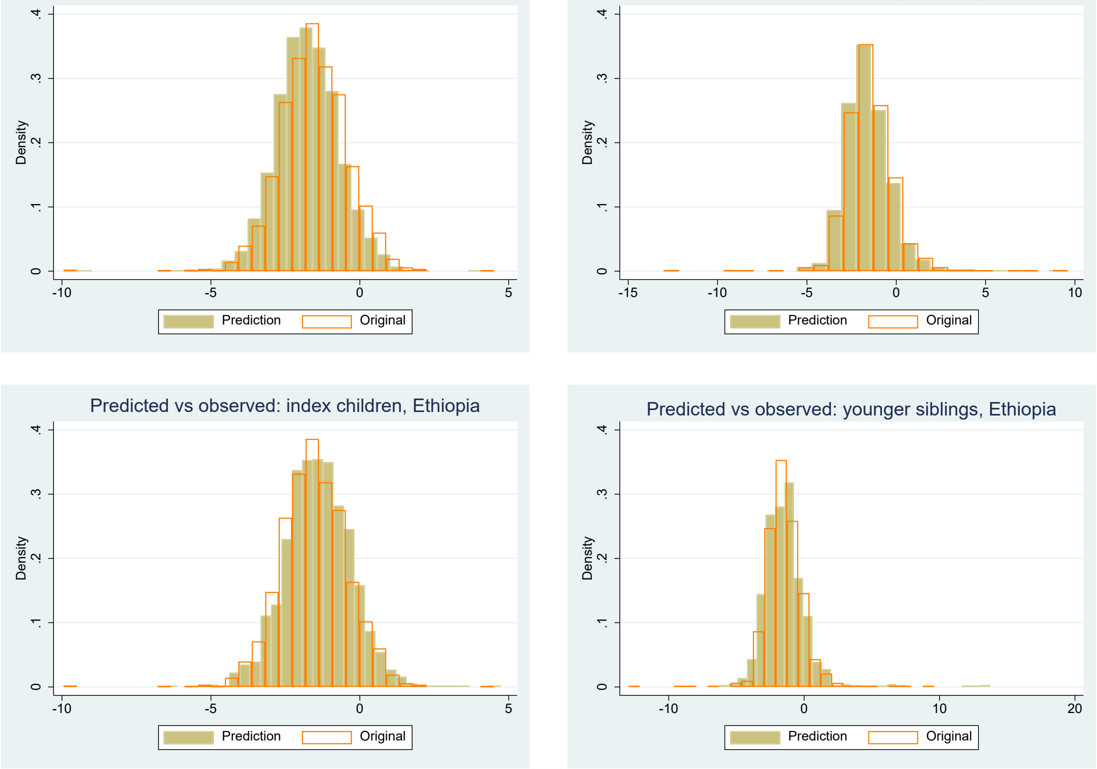
$$haz_i^* = \widehat{a_0} + \widehat{a_1} 60 + \widehat{a_2} 60^2 + \cdots + \widehat{a_p} 60^p + \widehat{u_\imath} \qquad \text{(b)}$$

replacing $\widehat{u_\imath}$ according to equation (b), we have that:

$$haz_i^* = haz_i + \widehat{a_1}(60 - age_i) + \widehat{a_2}(60^2 - age_i^2) + \cdots + \widehat{a_2}(60^p - age_i^p) \qquad \text{(b')}$$

Expression (b') can be used to adjust HAZ to a value that is closer to what would have been observed by a given child at the age of 60 months. We estimate this relationship by country and by group (index children and younger siblings separately). The latter is because the nature of the non-linear relationship between HAZ differs by group. We select a model with a polynomial of second degree. The predicted values are reported in **Figure B2**

Figure B2: Predicted versus observed: index children and younger siblings



APPENDIX C

Table C1: Main results, all coefficients

	Peru				Ethiopia			
	WM	IC	LM	IL	WM	IC	LM	IL
	coef/t	**coef/t**	**coef/t**	**coef/t**	**coef/t**	**coef/t**	**coef/t**	**coef/t**
Stunted	-0.102***	-0.051*	0.052	0.001	-0.051	-0.038	-0.126***	0.011
	(0.026)	(0.029)	(0.044)	(0.035)	(0.038)	(0.022)	(0.037)	(0.017)
Age in months, r4	0.012	0.000	0.027**	-0.007	-0.004	0.003	-0.014*	0.003
	(0.014)	(0.007)	(0.011)	(0.009)	(0.008)	(0.006)	(0.008)	(0.005)
Age in months squared, r4	-0.000	0.000	-0.000	0.000	0.000	-0.000	0.000*	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Child is female	-0.297***	-0.124***	0.030	-0.158***	-0.210***	-0.066**	-0.087**	-0.065**
	(0.028)	(0.025)	(0.049)	(0.045)	(0.026)	(0.031)	(0.033)	(0.026)
Maternal edu: complete primary	0.061	-0.012	0.056	0.017	0.024	-0.012	-0.004	0.032
	(0.047)	(0.029)	(0.075)	(0.065)	(0.052)	(0.021)	(0.035)	(0.028)
Maternal edu: complete secondary	0.082	0.031	0.201**	0.001	0.027	-0.005	0.067	0.005
	(0.064)	(0.040)	(0.071)	(0.059)	(0.048)	(0.037)	(0.056)	(0.032)
Maternal edu: complete tertiary	0.181**	0.055	0.287***	0.006	-0.070	-0.029	0.119*	-0.004
	(0.077)	(0.049)	(0.098)	(0.066)	(0.058)	(0.038)	(0.067)	(0.050)
Urban area	0.138**	-0.010	0.173*	-0.007	0.022	0.034	0.442**	0.100
	(0.051)	(0.042)	(0.087)	(0.051)	(0.150)	(0.093)	(0.198)	(0.091)
Household size	-0.015**	-0.007	-0.004	0.005	0.006	-0.000	-0.004	-0.001
	(0.007)	(0.008)	(0.010)	(0.006)	(0.009)	(0.006)	(0.008)	(0.004)
Wealth index - quintile 2	0.026	-0.008	0.011	0.035	0.102**	0.009	0.004	0.045
	(0.048)	(0.027)	(0.072)	(0.055)	(0.042)	(0.037)	(0.046)	(0.031)
Wealth index - quintile 3	0.020	0.075**	0.110	0.068	0.074*	0.021	0.036	0.052*
	(0.051)	(0.034)	(0.073)	(0.044)	(0.043)	(0.030)	(0.049)	(0.029)
Wealth index - quintile 4	0.080	0.074	0.213**	0.158**	0.150***	0.053	0.134**	0.069**

	(0.070)	(0.056)	(0.090)	(0.069)	(0.048)	(0.033)	(0.059)	(0.032)
Wealth index - quintile 5 (top)	0.102	0.109*	0.157	0.152**	0.094	0.115*	0.216**	0.080
	(0.067)	(0.060)	(0.115)	(0.062)	(0.065)	(0.060)	(0.087)	(0.047)
Maternal native tongue: spanish	0.076	0.055	0.021	0.198**				
	(0.066)	(0.055)	(0.068)	(0.073)				
Maternal native tongue: oromifah					-0.048	0.013	-0.246***	-0.054
					(0.102)	(0.054)	(0.067)	(0.077)
Maternal native tongue: tigrina					0.127	-0.004	0.175***	0.149**
					(0.185)	(0.098)	(0.058)	(0.071)
Maternal native tongue: other					-0.175**	0.062	-0.110	-0.052
					(0.069)	(0.057)	(0.113)	(0.045)
hr==9 am to 4pm	-0.028	-0.095	0.003	-0.060	-0.014	0.011	0.037	0.012
	(0.130)	(0.063)	(0.059)	(0.065)	(0.047)	(0.030)	(0.078)	(0.018)
hr==5pm to 12 am	-0.060	-0.061	0.006	-0.035	-0.081	0.015	0.267	0.041
	(0.113)	(0.066)	(0.082)	(0.092)	(0.080)	(0.044)	(0.200)	(0.045)
(mean) wkend	-0.013	-0.002	0.020	0.047	0.006	0.055**	0.032	0.018
	(0.029)	(0.029)	(0.050)	(0.039)	(0.036)	(0.021)	(0.025)	(0.022)
Child is a Younger Sibling	0.270*	0.140*	0.278**	0.218**	0.017	0.035	0.171**	0.002
	(0.137)	(0.079)	(0.111)	(0.090)	(0.090)	(0.058)	(0.065)	(0.055)
Child is an Older Sibling	(dropped)	(dropped)	(dropped)	(dropped)	0.101	0.026	-0.030	0.119*
					(0.085)	(0.076)	(0.064)	(0.057)
Baseline task	0.448***	0.546***	0.195***	0.708***	0.485***	0.548***	0.280***	0.721***
	(0.025)	(0.037)	(0.021)	(0.100)	(0.023)	(0.017)	(0.036)	(0.070)
_cons	-0.914	-0.124	-2.300***	-0.067	0.080	-0.243	0.483	-0.302
	(0.696)	(0.443)	(0.596)	(0.472)	(0.655)	(0.457)	(0.521)	(0.371)
Number of observations	2,497	2,501	2,501	2,491	2,901	2,901	2,901	2,900
Adjusted R2	0.310	0.390	0.080	0.517	0.289	0.353	0.268	0.638

Note: These results correspond to those reported in Table 5 for Ethiopia and Peru. Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

Table C2: Impact of nutritional status on foundational cognitive skills – household fixed effects model controlling for birth order and birth-sex order

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Pooled sample	Coef.	-0.130***	-0.062**	0.006	-0.000
	Std. Error	(0.043)	(0.029)	(0.048)	(0.035)
Peru	Coef.	-0.149**	-0.049	0.024	0.016
	Std. Error	(0.068)	(0.052)	(0.085)	(0.065)
Ethiopia	Coef.	-0.094	-0.067*	-0.028	-0.004
	Std. Error	(0.057)	(0.035)	(0.057)	(0.040)
Sample size					
Peru		716	716	716	716
Ethiopia		1,158	1,158	1,158	1,158

Note: All coefficients are standardized. Each coefficient comes from a different estimation linking stunting to a given FCS. Results come from an OLS specification that regresses siblings-difference in a given FCS on siblings-difference in stunting, controlling for: (i) sibling-differences in age; (ii) sibling-differences in: early-life wealth index, early-life area of location, and early-life household size; (iii) sibling-differences in performance in: baseline tasks, whether the task was administered during the weekend, and the time of the day when the tasks were administered; (iv) whether the index child was the first born; (v) birth-sex order dummies. * p<0.1 ** p<0.05 *** p<0.01.

Table C3: Impact of nutritional status on foundational cognitive skills – using unadjusted stunting

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A: multivariate OLS					
Pooled sample	Coef.	-0.081***	-0.053***	-0.078***	-0.004
	Std. Error	(0.025)	(0.017)	(0.027)	(0.018)
	Adjusted R2	0.313	0.386	0.185	0.574
Peru	Coef.	-0.140***	-0.068**	-0.011	-0.031
	Std. Error	(0.031)	(0.028)	(0.038)	(0.033)
	Adjusted R2	*0.309*	*0.388*	*0.078*	*0.519*
Ethiopia	Coef.	-0.023	-0.038*	-0.128***	0.022
	Std. Error	(0.035)	(0.021)	(0.036)	(0.015)
	Adjusted R2	*0.287*	*0.352*	*0.268*	*0.639*
Panel B: household fixed effects					
Pooled sample	Coef.	-0.102**	-0.069**	0.006	-0.003
	Std. Error	(0.045)	(0.029)	(0.046)	(0.035)
Peru	Coef.	-0.147**	-0.100*	0.026	-0.010
	Std. Error	(0.073)	(0.055)	(0.082)	(0.065)
Ethiopia	Coef.	-0.055	-0.065*	-0.002	0.003
	Std. Error	(0.059)	(0.035)	(0.054)	(0.042)
Sample size					
Peru		2,496	2,501	2,495	2,491
Ethiopia		2,909	2,915	2,903	2,914

Note: All coefficients are standardized. Each coefficient comes from a different estimation linking stunting (as observed in the dataset, using the observation closest to age of five) to a given FCS. Results from panel A correspond to equation (1) (pooled OLS). Controls included: child´s age (in months) and sex; native tongue of the mother and maternal education; wealth index (in quintiles) at age 1, area of location at age 1, household size at age 1; community fixed effects at age 1 (specific to the index child); performance in the baseline tasks, whether the task was administered during the weekend, and the time of the day when the tasks were administered. Results from panel B correspond to a household fixed effects specification (equation (2)). Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

Table C4. Impact of nutritional status on foundational cognitive skills – excluding baseline tasks as controls

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A: multivariate OLS					
Pooled sample	Coef.	-0.126***	-0.076***	-0.030	-0.043
	Std. Error	(0.028)	(0.020)	(0.030)	(0.034)
	Adjusted R2	*0.108*	*0.162*	*0.128*	*0.083*
Peru	Coef.	-0.124***	-0.050	0.050	-0.017
	Std. Error	(0.039)	(0.037)	(0.046)	(0.050)
	Adjusted R2	0.123	0.170	0.048	0.090
Ethiopia	Coef.	-0.110**	-0.106***	-0.110***	-0.068
	Std. Error	(0.044)	(0.024)	(0.036)	(0.047)
	Adjusted R2	0.056	0.112	0.189	0.058
Panel B: household fixed effects					
Pooled sample	Coef.	-0.154***	-0.090***	0.021	-0.046
	Std. Error	(0.048)	(0.034)	(0.049)	(0.048)
Peru	Coef.	-0.102	-0.068	0.024	-0.010
	Std. Error	(0.072)	(0.065)	(0.090)	(0.088)
Ethiopia	Coef.	-0.157**	-0.121***	-0.025	-0.079
	Std. Error	(0.064)	(0.039)	(0.057)	(0.058)
Sample size					
Peru		2,497	2,501	2,501	2,491
Ethiopia		2,901	2,901	2,901	2,900

Note: All coefficients are standardized. Each coefficient comes from a different estimation linking stunting to a given FCS. Results from panel A correspond to a variant of equation (1) (pooled OLS), excluding the baseline tasks as control variables. Similarly, results from panel B correspond to a variant of equation (2) (household fixed effects), excluding the baseline tasks as control variables. Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

Table C5. Impact of nutritional status on performance at baseline tasks

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A: multivariate OLS					
-					
Pooled sample	Coef.	-0.101***	-0.056***	0.025	-0.075*
	Std. Error	(0.028)	(0.020)	(0.027)	(0.037)
	Adjusted R2	*0.050*	*0.172*	*0.078*	*0.050*
Peru	Coef.	-0.049	0.003	-0.008	-0.029
	Std. Error	(0.043)	(0.031)	(0.043)	(0.050)
	Adjusted R2	*0.058*	*0.128*	*-0.001*	*0.057*
Ethiopia	Coef.	-0.121***	-0.124***	0.058*	-0.111*
	Std. Error	(0.038)	(0.020)	(0.033)	(0.055)
	Adjusted R2	*0.047*	*0.094*	*0.114*	*0.039*
Panel B: household fixed effects					
-					
Pooled sample	Coef.	-0.078	-0.059*	0.037	-0.074
	Std. Error	(0.053)	(0.033)	(0.051)	(0.055)
Peru	Coef.	0.079	-0.034	0.009	0.002
	Std. Error	(0.092)	(0.062)	(0.083)	(0.086)
Ethiopia	Coef.	-0.144**	-0.106***	0.044	-0.114
	Std. Error	(0.065)	(0.038)	(0.065)	(0.072)
Sample size					
Peru		2,497	2,501	2,501	2,494
Ethiopia		2,901	2,901	2,901	2,901

Note: All coefficients are standardized. Each coefficient comes from a different estimation linking stunting to a child´s performance in each baseline task. Results from panel A correspond to a pooled OLS specification. Controls included: child´s age (in months) and sex; native tongue of the mother and maternal education; wealth index (in quintiles) at age 1, area of location at age 1, household size at age 1; community fixed effects at age 1 (specific to the index child); whether the task was administered during the weekend, and the time of the day when the tasks were administered. Results from panel B correspond to a household fixed effects specification controlling for the same variables. Standard errors (reported in parentheses) are clustered at cluster level. * p<0.1 ** p<0.05 *** p<0.01.

Table C6: Impact of nutritional status on foundational cognitive skills – using HAZ as the nutritional indicator

		Working memory (WM)	Inhibitory control (IC)	Long-term memory (LM)	Implicit learning (IL)
		(1)	**(2)**	**(3)**	**(4)**
Panel A: multivariate OLS					
-					
Pooled sample	Coef.	0.042***	0.029***	0.023**	0.012
	Std. Error	(0.012)	(0.008)	(0.011)	(0.008)
	Adjusted R2	*0.316*	*0.389*	*0.185*	*0.572*
Peru	Coef.	0.052***	0.039***	-0.004	0.013
	Std. Error	(0.014)	(0.013)	(0.017)	(0.015)
	Adjusted R2	*0.310*	*0.391*	*0.079*	*0.517*
Ethiopia	Coef.	0.031	0.021**	0.049***	0.013*
	Std. Error	(0.018)	(0.010)	(0.012)	(0.007)
	Adjusted R2	*0.290*	*0.353*	*0.268*	*0.639*
Panel B: household fixed effects					
-					
Pooled sample	Coef.	0.044**	0.013	-0.002	0.011
	Std. Error	(0.019)	(0.013)	(0.021)	(0.015)
Peru	Coef.	0.005	-0.005	-0.004	0.003
	Std. Error	(0.030)	(0.024)	(0.040)	(0.030)
Ethiopia	Coef.	0.054**	0.022	0.014	0.021
	Std. Error	(0.025)	(0.016)	(0.024)	(0.016)
Sample size					
Peru		2,497	2,501	2,501	2,491
Ethiopia		2,901	2,901	2,901	2,900

Note: All coefficients are standardized. Each coefficient comes from a different estimation linking height-for-age Z-score (HAZ) to a given FCS. Results from panel A correspond to equation (1) (pooled OLS). Controls included: child´s age (in months) and sex; native tongue of the mother and maternal education; wealth index (in quintiles) at age 1, area of location at age 1, household size at age 1; community fixed effects at age 1 (specific to the index child); performance in the baseline tasks, whether the task was administered during the weekend, and the time of the day when the tasks were administered. Results from panel B correspond to a household fixed effects specification (equation (2)). Standard errors (reported in parentheses) are clustered at cluster level. * $p<0.1$ ** $p<0.05$ *** $p<0.01$.