

## Home Learning Environment and Physical Development Impact Children's Executive Functions and Literacy in Rural Côte d'Ivoire

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### **Abstract**

Previous research suggests executive functions mediate the effects of socioeconomic status (SES) on literacy. However, this research has primarily focused on high-income countries. Comparatively less is known about the mechanisms that link SES and literacy in low-and-middle-income countries, where childhood experiences of poverty are consistently linked to cognitive development through two sets of predictors: a child's physical development reflective of adequate nutrition and educational scaffolding at home (i.e. home learning environment). The influence of children's physical development and home learning environment (i.e., family literacy, caregiver interactions) on executive functions and literacy was examined in 630 primary-school children (6-14 years) in rural Côte d'Ivoire. SES had an indirect effect on literacy, mediated by executive functions. The home learning environment and a child's physical development showed distinct contributions to executive functions. The results suggest that improved home learning environments and supplemented nutrition could support executive function development and reduce the negative impact of socioeconomic disadvantage on literacy.

*Keywords:* Socioeconomic status (SES), Executive functions, Literacy, Côte d'Ivoire

## Introduction

Low-resource environments characterized by material deprivation, reduced language exposure, and nutritional deprivation are negatively associated with children's cognitive and language development outcomes, and in turn, children's academic outcomes, including literacy (Conger et al., 2010; Lipina et al., 2013; Lozoff et al., 2000; Lozoff et al., 2013). Childhood socioeconomic status (SES), as an indicator of a child's environment and experience of poverty, is therefore a powerful predictor of developmental and academic outcomes. However, our understanding of these crucial links between SES, cognitive development, and academic achievement is limited because studies relating these variables are overwhelmingly focused on industrialized nations where children in poorly resourced environments are contrasted with their relatively wealthy peers in the same classrooms or regions (Lawson & Farah, 2017; Tomalski et al., 2013; Ursache & Noble, 2016). Compared to children in high-income countries (HICs), children in low-resource households in low- and middle-income countries (LMICs) face a disproportionate burden of risk factors that undermine cognitive development: households often survive on less than \$1.90 USD per day (international poverty line; World Bank, 2016); undernutrition, stunting (impaired growth and development resulting from poor nutrition, infection, and inadequate psychosocial stimulation; WHO, 2022), and infectious disease are prevalent; and illiteracy rates are high. Many of the social and economic variables related to SES (i.e., parental income, occupation, education) that have been widely recognized in the broader literature as impactful on developmental and educational outcomes are not easily generalized from industrialized economies to agricultural communities in LMICs, thereby limiting our ability to draw universal conclusions about environmental influences on child development.

Childhood experiences of poverty in LMICs have been consistently linked to cognitive development through two sets of predictors: nutrition to support physical development (henceforth referred to as physical development), and the availability of quality care, stimulation, and educational scaffolding at home (henceforth referred to as home learning environment) (Obradović et al., 2019; Obradović, Yousafzai, et al., 2016). These predictors interact as a complex set of correlated variables linked to family SES (Nelson, 2007) and have been linked to executive functions (EF) development. EF are a set of cognitive skills that allow children to shift their attention to relevant information and suppress distractions in their environment, manipulate information mentally, and control their impulsive behavior. EF strongly support academic achievement. EF allow an emerging reader to allocate their attention towards processing written language and maintain and manipulate phonological and visual information in working memory that is required for skilled reading.

Here we ask how household SES relates to EF and literacy skills for children in rural Côte d'Ivoire. Indeed, the negative association between low SES and academic outcomes, including literacy, has previously been found to be mediated by the development of EF both in LMICs and HICs (Dilworth-Bart, 2012; Ferguson et al., 2013; Lawson & Farah, 2017; Nesbitt et al., 2013; Suntheimer et al., 2022). We test the hypothesis that EF mediate the association between SES and literacy. Specifically, we examine two distinct components related to SES, the home learning environment (i.e., educational scaffolding in the home) and physical development (i.e., children's weight and stature for their age – physical growth reflective of nutritional status). Focusing on rural sub-Saharan Africa's social and cultural context, we aimed to broaden our understanding of how these components of a child's environment support their cognitive development and literacy outcomes.

## **Executive Functions and Literacy**

Literacy is a complex skill that is dependent on multiple linguistic and cognitive abilities, including EF. EF encompass three distinct and highly correlated components: inhibition, working memory, and cognitive flexibility, albeit the magnitude of correlations between these components varies by age, assessment, and population (Best et al., 2009). These EF components support the development of more sophisticated skills, such as reasoning, planning, and problem-solving (Diamond, 2013). Children's EF in preschool and kindergarten significantly predict literacy (Cartwright, 2012; Foy & Mann, 2013), suggesting that EF have a direct impact on learning processes involved in literacy. These findings corroborate other studies showing that earlier intervention for EF development facilitates learning in multiple domains, including literacy (Best et al., 2011; Malloy-Diniz et al., 2008).

EF is implicated in word decoding (i.e., the ability to use orthographic patterns to access pronunciations and read words quickly and accurately) and reading comprehension (Nouwens et al., 2021; Ober et al., 2020; Sesma et al., 2009). The components of EF (inhibition, working memory, cognitive flexibility) contribute to word decoding in different ways. Inhibition is the ability to overcome automatic responses that might otherwise distract the reader from developing a new skill (Booth et al., 2010; Monette et al., 2011). During literacy development, inhibitory control supports an emerging reader by suppressing irrelevant and distracting information both in their environment and in their prepotent responses to the visual stimulus of written language (Altemeier et al., 2008; Dehaene et al., 2015). Working memory allows the reader to retain and manipulate the phonological and visual information necessary to learn the mappings between written language and its corresponding sounds and meanings—decoding ability (Ferreira et al., 2013). Cognitive flexibility, the ability to switch between different cognitive tasks, allows an

emerging reader to think about the properties of words beyond their semantic information and develop the meta-linguistic knowledge to understand the segmental nature of language, which in turn allows the reader to map segments to individual symbols (e.g. phonological awareness; Colé et al., 2014). A recent meta-analysis demonstrated a consistent role of EF in word decoding (Ober et al., 2020).

EF are also implicated in reading comprehension. The simple view of reading (Gough & Tunmer, 1986) posits that reading comprehension depends on two foundational skills: language comprehension and decoding. EF-related differences in decoding skills, therefore, affect reading comprehension. EF also accounts for individual variation in reading comprehension beyond decoding (Nouwens et al., 2021). Previous research has also found that working memory, planning, and sustained attention account for significant and unique variance in reading comprehension outcomes (e.g. Follmer, 2018).

Research in SSA specifically has also documented the links between EF and literacy. For example, in Ghana, a large longitudinal study (N=3,862) of EF, socio-emotional skills, and literacy and numeracy in children ( $M_{\text{age}}=5.2$  years, range=3-11 years) showed that early EF predicted higher literacy and numeracy skills (Wolf & McCoy, 2019). In Kenya, a study of 1,480 4-7 year-old children found that EF were associated with measures of early literacy and numeracy (Willoughby et al., 2019). Similarly, a study of 2,500 primary school students ( $M_{\text{age}}=8.65$  years, range=3-18 years) in Côte d'Ivoire found that EF related to children's literacy and numeracy skills across the school year (Finch et al., 2022). A study of older children (7<sup>th</sup> grade,  $M_{\text{age}}=13$  years) in Zambia further found a link between EF and reading comprehension (Namakando, 2021).

## **SES and Executive Functions**

A child's SES strongly predicts the development of EF. Socioeconomically disadvantaged environments characterized by economic insecurity, nutritional deficiencies, and poor stimulation may undermine the development of basic cognitive skills, including EF. EF is particularly vulnerable to environmental effects because it continues to develop during childhood and through adolescence into adulthood progressively (Dilworth-Bart, 2012; Ferguson et al., 2013; Hackman et al., 2010; Lawson & Farah, 2017; Mazuka et al., 2009; Miyake et al., 2000; Nesbitt et al., 2013). The brain region that supports EF—the prefrontal cortex—is late to mature and consequently remains sensitive to environmental effects throughout childhood. Indeed, research shows that a child's social and economic environment influences the development of the prefrontal cortex, and in turn, EF (Finn et al., 2017; Noble et al., 2015; Tooley et al., 2020; Ursache & Noble, 2016).

Researchers exploring the mechanisms underlying the negative effects of socioeconomic disadvantage (i.e. low SES) on EF and have begun to identify how proximal experiences shape EF. Evidence suggests that two sets of predictors associated with low SES, physical development and the home learning environment, play a role in children's EF development (Hackman et al., 2010; Obradović & Willoughby, 2019). For example, research on children growing up in India has demonstrated a link between EF development and nutrition. As measured by stunting, severe malnutrition was related to poorer EF, particularly emotional control and working memory (Selvam et al., 2018). In rural Pakistan, children's height-for-age at 24 months was related to EF in preschool, independent of family food insecurity, socioeconomic resources, and stimulating environments (Obradović & Willoughby, 2019). The impact of nutrition on EF has also been demonstrated in adult populations in Iran, where a positive relation was found between self-

reports of nutrition and cognitive flexibility (Khodarahimi, 2018). Importantly, physical growth uniquely predicts EF, independent of the effect of biological growth on general cognition (Black et al., 2017; Obradović & Willoughby, 2019).

Beyond the impact of physical development on children's EF development, the home learning environment also predicts EF development (Haft & Hoefl, 2017). Sarsour et al. (2011) showed that family SES inequalities were associated with the home environment and children's EF. Specifically, responsive parenting, enrichment activities, and family companionship mediated the link between SES and child inhibitory control and working memory. Home literacy environments were also found to be positively associated with EF development. For example, a study in Argentina of 75 mother-infant dyads (age 18-24 months) found that the presence of books and frequency of literacy activities was positively associated with EF skills (Gago Galvagno et al., 2020). Similarly, in Zambia (N=2,711, M<sub>age</sub>=6.21years, range=5.58-7 years), at-home literacy activities were related to 6-year-olds' EF (McCoy et al., 2015).

Theoretical models that link SES and EF development posit stress hormones as the primary mechanism by which early adverse experiences (including under-stimulating environments, poor quality caregiving, and socioeconomic disadvantage [low SES]) influence EF development (Blair et al., 2011; Blair & Raver, 2012; Obradović, Portilla, et al., 2016). One of the central physiological systems implicated in response to adversity is the hypothalamic-pituitary-adrenal axis (HPAA), which secretes cortisol (a glucocorticoid) in response to stressful experiences. Childhood experiences of socioeconomic disadvantage have been linked to increased cortisol levels, which may undermine the maturation and neural activity in regions known to support EF, and lower performance on EF tasks (Depasquale et al., 2021; Evans & English, 2002; Lupien et al., 2007). Cortisol levels are also significantly affected by malnutrition

(Rao et al., 1968). Cortisol levels are higher in infants and young children who experience malnutrition; indeed, perinatal and infantile malnutrition is strongly linked to HPA activity across the life-span (Kajantie, 2006; Malozowski et al., 1990). The biological mechanisms linking nutritional status and cortisol are complex; for example, malnutrition is also associated with glucocorticoid receptor activity in addition to increased cortisol levels (Manary et al., 2006). Increased cortisol levels and malnutrition are both associated with increased infection and inflammation, which is linked to poor neurodevelopmental outcomes later in childhood (Jiang et al., 2018).

However, moderately increased cortisol levels have also been linked with improved EF performance and individual differences in cortisol responsivity moderate the effects of children's environments on their behavior. This suggests that some children may be more susceptible than others to environmental influences (Ellis et al., 2011; Obradović, 2016) (Obradović, Portilla, et al., 2016). Differential susceptibility is a useful model for understanding how early childhood experiences influence EF development. Existing evidence linking low SES with HPA activity points to multiple (and potentially additive) pathways by which low SES is associated with EF development (i.e. secreted cortisol levels, glucocorticoid receptor activity, inflammation) suggesting that experiences associated with low SES, such as poor nutrition and low-quality caregiving, may have distinct physiological impacts on EF development.

### **SES and Literacy in LMICs**

A child's socioeconomic environment is key to their literacy development. A recent study of 312 sets of twins (age range=3-11 years) in a high-income region (Hong Kong) pointed to environmental rather than heritable explanations for the connection between SES and literacy (Chow et al., 2017). Furthermore, an analysis of the relation between SES and literacy across

dozens of countries participating in the Programme for International Student Assessment (PISA) education survey distinguished household income (a component of SES) as a significant predictor of literacy outcomes (OECD, 2016). However, the mechanisms that relate SES and literacy outcomes are not uniform across low- and middle-income countries (LMICs) and high-income countries (HICs). In the PISA survey, the relation between income and literacy held mainly for low gross domestic product (GDP) countries. In contrast, in higher GDP countries, parent education was the most important predictor for literacy (O'Connell, 2019). Moreover, the PISA survey includes very little representation of the world's poorest nations and no representation in sub-Saharan Africa. Even the lowest-income countries represented in the survey surpass Côte d'Ivoire in GDP per capita. It is possible, then, that the relation between SES and literacy in the context of Côte d'Ivoire may differ and implicate additional factors associated with socioeconomic disadvantage more prevalent in low-income countries.

SES is both directly and indirectly related to literacy outcomes. For example, limited monetary resources in lower SES households may directly hinder children's access to books, tutors, and other educational resources to support literacy (Tichnor-Wagner et al., 2016). Multiple studies have pointed to the presence of books in the home as significantly supporting the development of critical skills for literacy, such as phonological awareness and expressive vocabulary, as well as reading comprehension (Mol & Bus, 2011; Yeo et al., 2014; Zuilkowski et al., 2019).

Parental education and the home literacy environment (e.g., a literate adult who can aid a child with schoolwork) indirectly shape children's literacy. Nurturing activities like reading a story to the child before bed are associated with better literacy skills (Sénéchal & Lefevre, 2002). For example, engaging in literacy activities with a parent or caregiver at home influences early

literacy success (Zuilkowski et al., 2019). In LMICs, children's opportunities for these scaffolding activities may be limited by parents' education, particularly in regions with high adult illiteracy.

Given that EF is associated with both SES and academic achievement, EF has been proposed to mediate SES and academic achievement, including literacy. Indeed, several studies have implicated EF in SES-related gaps in academic achievement, including both school readiness (Dilworth-Bart, 2012; Fitzpatrick et al., 2014; Micalizzi et al., 2019) and school achievement across childhood and adolescence (Lawson & Farah, 2017; Nesbitt et al., 2013; Sektnan et al., 2010; Waters et al., 2021). Moreover, differential contributions of SES indicators (e.g., parent education, income) to academic outcomes have been documented (Davis-Kean et al., 2021), albeit the majority of this research has focused on SES indicators in HICs. The specific pathways by which socioeconomic disadvantage contributes to literacy outcomes in LMICs have remained largely unaddressed.

### **Rural Côte d'Ivoire**

Rural communities in Côte d'Ivoire face numerous obstacles to education and literacy. In 2014, approximately half of the adult population of Côte d'Ivoire was illiterate; the literacy rate (15 years old and older) was 43.9% (UNESCO Institute for Statistics, 2014) and fewer than two-thirds of adults completed their primary school education (UNESCO, 2016). According to the State Report on the National Education System of Côte d'Ivoire (school statistics from the Ministry of National Education, 2019), the school-age population (children aged 6-15) will increase to about 1.5 million by 2025. This fast-rising population will create significant economic opportunities for the country. Realizing the economic opportunities of Côte d'Ivoire's population growth depends on improving learning outcomes and school participation. Although

the primary school net enrollment rate is 91.1%, only 73.26% of children will complete primary school (UNESCO, 2016; UNESCO Institute for Statistics, 2014). The age at which a child begins their schooling is highly variable. Children may start school as young as four years of age or as old as 12, and grade repetition and absenteeism are prevalent, contributing to poor educational outcomes (Heugh, 2011; PASEC, 2014).

For children who do enroll and attend school, academic outcomes remain poor for many. 82.2% of students fail to reach grade-appropriate numeracy levels, and 77.9% of children fail to reach grade-appropriate literacy levels by the end of primary school (PASEC, 2020). Overall, 73% of CE1 (Grade 3) students master less than half of the target language, literacy, and mathematics skills for their grade level (UNESCO, 2016). This academic achievement gap is the widest for children in rural areas (UNESCO, 2016), where a high percentage of children cannot read (Ball et al., 2022; Jasińska et al., 2022; Sobers et al., under review). Importantly, rural areas are among the poorest regions in Côte d'Ivoire, and children in these regions may be particularly vulnerable to the negative impact of low-resource environments on educational outcomes.

Low SES environments in rural Côte d'Ivoire are characterized by low parental education and literacy and limited household income, often below the poverty definition of \$1.90 USD per day (World Bank, 2016). These circumstances can limit parents' ability to provide literacy materials and engage in literacy activities with their children and adequately nourish their children. In Côte d'Ivoire, 21.6% of children are stunted (low height-for-age). Poor nutrition experienced by children can have a lasting impact on their cognitive and emotional outcomes (Grantham-McGregor, 1995). However, the specific consequences of undernutrition for cognitive development, and in turn, academic outcomes are not fully understood.

## **Current Study**

The present study aimed to better understand environmental impacts on children's EF development and literacy in rural Côte d'Ivoire, where the relevant distribution of resources can be very different from previously studied populations in HICs—as well as many previously reported studies of SES and literacy in LMICs. Although there is an ongoing debate about the measurement of SES and its specific causal role in educational outcomes, the superficial correlation between these variables is widely attested, with a likely mediating role for EF. Moreover, the form that SES and EF variability take in Côte d'Ivoire may differ from other studied contexts. Poverty and severe developmental risk factors (malnutrition, illness, and environmental hazards) shape children's economic realities and neurocognitive outcomes in ways generally not studied in the literature on literacy development.

In the analyses that follow, we examined SES using indices both relevant and measurable in the rural Ivorian context, in relation to children's EF and literacy skills, using widely-used standardized tasks adapted for low-resource rural settings. Using structural equation modeling, we examined specific pathways, the home learning environment and children's physical development, that link SES to children's EF and literacy skills. We also examined how education-relevant factors such as owning a school book predicted literacy and the links between age and physical and cognitive development, and literacy outcomes.

We hypothesized that children's EF skills would, at least in part, mediate the relation between SES and literacy. More specifically, SES would be associated with a child's home learning environment (including parental literacy, and parental academic support) and physical development, and each would distinctly contribute to EF skills. Therefore, we predicted that (1) children from lower-SES households would show poorer EF skills, and as a consequence of poor

EF, poorer literacy outcomes as well, and (2) different poverty-related components of children's environment (i.e., poor home learning environment, poor physical development associated with poor nutrition) will mediate the impact of SES on EF and, in turn, literacy. Understanding the contributions of specific environmental components would provide nuanced insights into the complexities of the relation between SES, EF, and literacy in Côte d'Ivoire and provide us with new information about how best to support literacy in this region.

## **Methods**

### **Participants**

Six hundred and thirty children ( $n=630$ ; 321 boys) between the ages of 6 and 14 years ( $M=9.56$ ;  $SD=2.07$ ) in the equivalent of first, third, and fifth grades (1st:  $n=124$ ; 3rd:  $n=255$ ; 5th:  $n=251$ ) enrolled in 14 public primary schools in Côte d'Ivoire participated in this study. The primary language of instruction in all schools was French, however, six schools incorporated a regional language as a language of instruction (see Ball et al., 2022) Children were part of a larger study examining literacy development in rural communities in Côte d'Ivoire. The data were collected during 2016-2018 in 10 villages in central and southern Côte d'Ivoire. Villages in cocoa-producing regions of Adzopé, Sikensi, Tiebissou, and Soubré, where the languages spoken are Attié, Abidji, Baoulé, and Bété, respectively, were selected for this study. Approximately 74% of children reported that their caregiver farmed, with cocoa the primary crop in the region. Children with any neurological or neurodevelopmental disorders were excluded from the study. However, it is uncommon in rural public schools in Côte d'Ivoire for diagnostic information about children's neurological and neurodevelopmental disorders to be recorded. Moreover, children with neurological or neurodevelopmental disorders rarely enroll in school in rural Ivorian communities. Thus, no children met our exclusion criteria. We note that some children

were unsure of their age (common in rural communities), in which case we used the school's demographic data to determine the child's age.

## **Measures**

### ***Home Environment Questionnaire***

Children were asked questions about their household, including the number of literate adults, whether the child received support with their academic activities from adults, and whether the child owned a schoolbook. Each child also completed a 15-item household inventory questionnaire, previously used as part of Early Grade Reading Assessment, EGRA (Gove & Wetterberg, 2011; RTI International, 2015) in West Africa (including Francophone countries of Mali and Senegal). The total household inventory score was used as an index of SES, following established protocols for measuring SES in low-resources communities in LMICs. Determining SES based on household assets rather than maternal education and household income is a more appropriate indicator of the relative status of a household in communities where income fluctuates throughout the seasons (Howe et al., 2012).

### ***Anthropometric***

Growth measures, height and weight, were collected using a standard scale and wall-mounted meter. Anthropometric indices were height-for-age (hfa) and BMI-for-age (bfa). Z-scores based on WHO global norms were calculated for these indices to determine the percentage of stunting (two SD below mean z-hfa) and wasting (two SD below mean z-bfa) in children following the World Health Organization protocol (WHO, 2008). There are no WHO global norms for weight-for-age above ten years old, so weight was used only in computing bfa.

### ***Executive Functions***

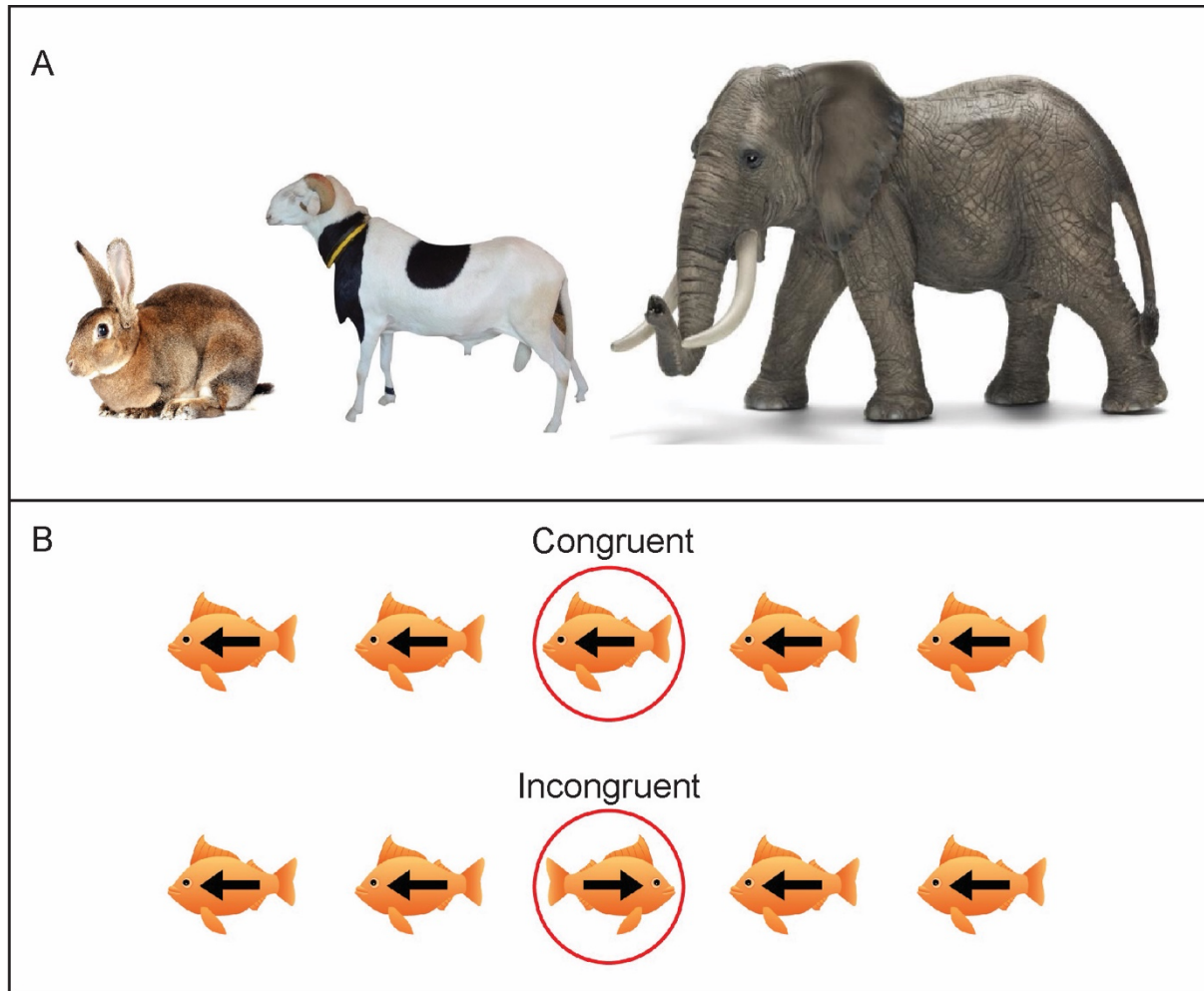
Children completed two EF tasks measuring working memory and inhibitory control.

**Working memory.** Working memory was measured using an adaptation of the List Sorting Working Memory Test, part of the NIH Toolbox Cognition Battery (Tulsky et al., 2013; Tulsky et al., 2014). In this task, a child saw sets of individually presented images of common animals (e.g., pig, rooster, elephant). The child was asked to remember the set images and mentally sort them in the order of increasing size (e.g., rooster, pig, elephant). First, the experimenter verified that the child knew the test animals by asking a child to name all images. Children were then given practice items with feedback and scaffolding from the experimenter before beginning the task. In part one of the task, trials started with two images of animals, each individually presented, then the child would be asked to recount these in ascending size order. If the child was successful, the experimenter would show three images of animals and the child would recount these in ascending size order. The number of images would continue to increase up to seven images. The task would terminate after the child failed to correctly recount the items they had seen or reached the set of seven.

In part two of the task, trials followed the procedure detailed above, but images of both animals and foods were included and presented again in increasing sets up to seven. Children were first asked to recount the animals and then recount the foods in ascending size order. This task is typically presented on a tablet, however, many of the children participating in this study had little or no experience with this type of interactive technology, and therefore a paper adaptation of the study was administered. Each image was presented on a separate page of a booklet. The child would see each image for approximately three seconds. The original images were replaced with more culturally-appropriate images (animals: butterfly, frog, mouse, bird, turtle, rabbit, rooster, dog, monkey, pig, goat, lion, cow, elephant; foods: peanuts, egg, lime, orange, onion, banana, corn, papaya, mango, coconut, pineapple) that would be familiar to the

children growing up in rural Côte d'Ivoire (Figure 1a). For example, blueberries were replaced by peanuts. Ivorian researchers validated these culturally-appropriate images. The task was scored based on the number of items in the last set that the child successfully completed in part one plus the number of items in the previous set that the child successfully completed in part two.

**Inhibitory control.** Inhibitory control was measured using the Flanker Task, based on Eriksen and Eriksen (1974) and later adapted by Rueda et al. (2004). The task measures a child's ability to inhibit distracting information and attend to pertinent information. This task is also part of the NIH Toolbox Cognition Battery (Zelazo et al., 2013), which we adapted to a paper-based version. Children saw a row of identical fish on a page and were asked to identify the orientation of the middle fish (i.e., left or right). The orientation of this middle fish might be congruent or incongruent with the surrounding fish (Figure 1b). The task was self-paced and consisted of ten congruent and ten incongruent trials. Although the Flanker task typically includes an RT measure, that was impossible for the paper version, and children were scored based on accuracy in incongruent trials.



*Figure 1.* A) Example items from the List Sorting Working Memory Test. B) Example congruent and incongruent items from the Flanker Task. Middle fish is circled for illustration, but it is not circled in the task. [color]

### ***Literacy Measures***

Children's literacy skills were measured using timed letter, word, and nonword reading subtests in the French language version of the EGRA (Ball et al., 2022; Jasińska et al., 2022), previously used in Senegal (Gove & Wetterberg, 2011; RTI International, 2015). Before beginning each subtest, children were given a practice trial where the experimenter provided feedback and scaffolding. Children were asked to read test items as quickly and accurately as

possible for each subtest. Experimenters marked incorrect items and terminated the task if the child failed to read the first ten items correctly or after 60 seconds had elapsed. These tasks have previously been used in Côte d'Ivoire (Ball et al., 2022; Jasińska et al., 2022; Sobers et al., under review)

**Letter reading.** Children were asked to read 100 letters or combinations of letters (grapheme clusters, e.g., “ch”)

**Word reading.** Children were asked to read 50 familiar French words (e.g. ‘monde,’ ‘kilo’).

**Nonword reading.** Nonword reading assessed a reader’s ability to decode novel words. Children were asked to read 50 mono- or bi-syllabic nonwords, which do not exist in French but conformed to French syllabic and phonotactic structure (e.g. ‘toche,’ ‘donré’).

## **Procedure**

Children completed all tasks one-on-one with trained researchers who were native speakers of Ivorian French. At a minimum, all researchers had a bachelor’s degree in a relevant field (education, psychology, linguistics, sociology). All testing took place at the child’s school, outside the classroom. See Jasińska and Guei (2018) for detailed informed consent procedure.

## **Analytic framework**

We applied structural equation modeling (SEM) to test how specific components of socioeconomic disadvantage (physical growth associated with poor nutrition, and the home learning environment) have a mediating effect on literacy through their impact on EF. Our SEM incorporated a set of measures of SES (household inventory), physical development (child anthropometric outcomes; height-for-age and BMI-for-age z-scores), and the home learning environment (literate parent, parent who can help with homework), whether a child owned a

schoolbook, executive functions (working memory, inhibitory control), and literacy (letter, word, nonword reading).

We constructed a SEM using the lavaan package (Rosseel, 2012) for R (The R Core Team, 2016). The model was estimated using weighted least squares estimation with robust means and variances (WLSMV; Bandalos, 2014; Cai & Moustaki, 2018; Flora & Curran, 2004; Rhemtulla et al., 2012) applying the Satorra-Bentler correction (Satorra & Bentler, 1994; Satorra & Bentler, 2001) to describe directional relations between three manifest variables (SES, Age, Owning a Schoolbook) and four latent variables (home learning environment, physical development, EF, and literacy). This method was preferable because of the inclusion of categorical variables (literate parent, homework help, and owning a schoolbook) and because inhibitory control, word reading, and nonword reading were skewed (Inhibitory Control: skewness of -2.63 and kurtosis of 9.50; Word: skewness of 1.23 and kurtosis of 3.29; Nonword: skewness of 1.59 and kurtosis of 4.85). We note that the log-transform of these variables was also skewed, so we retained the original non-transformed variables and applied the Satorra-Bentler correction for nonnormality. The Satorra-Bentler method incorporates a scaled chi-squared test with robust standard errors recommended for nonnormal variables Field (Curran et al., 1996; Hu et al., 1992) and is appropriate for larger sample sizes than 250 (Hu & Bentler, 1999; Yu, 2002).

Children occasionally misreport their age, resulting in extreme outlier values on height- and BMI-for-age scores. To limit the effect of these outliers, we identified 39 participants (6.2% of the sample) with height-for-age and BMI-for-age z-scores outside the range -4 to 4 SD and excluded them from the structural equation model. The overall cumulative distributions and median scores are depicted in Figure 3. Our SEM analysis included the subset of our sample for

whom all data were available (n=539; 3 children had missing literacy scores, 20 children had missing EF scores, and 38 children had missing questionnaire scores, corresponding to 0.5%, 3.2%, and 6% of the sample respectively).

We reasonably expected physical and cognitive development to change with age, a component that should be modeled separately from the relation between EF and literacy. Therefore, age was regressed on the three child variables (EF, physical development, and literacy), but not on the household variables (SES and home learning environment).

### **Transparency**

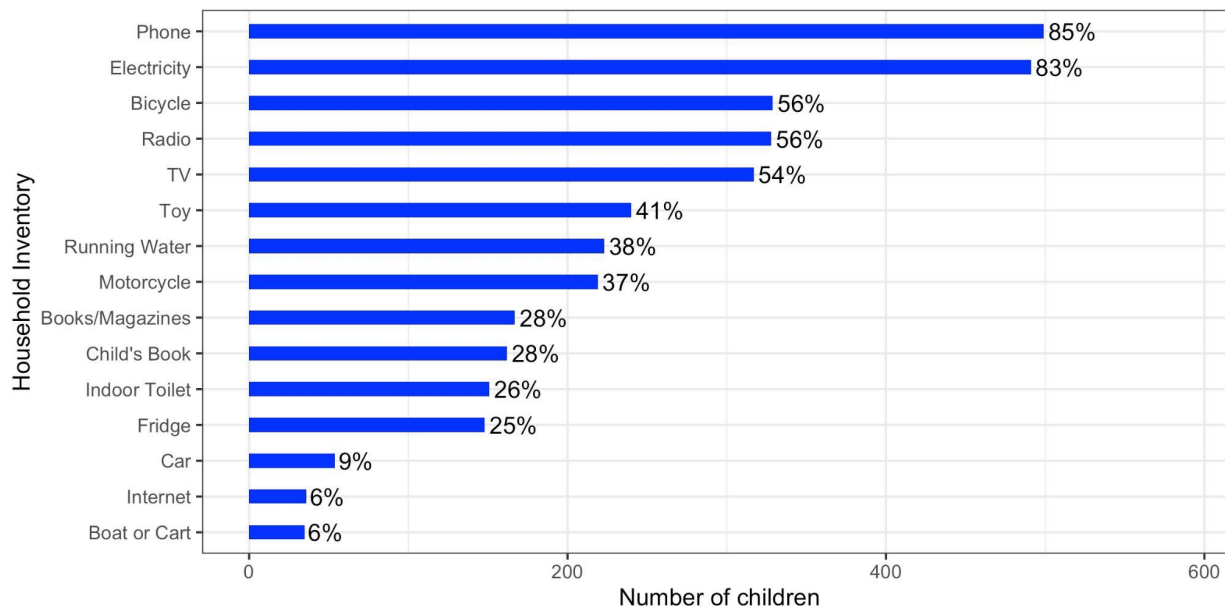
All measures, data, and data analysis scripts are available at <https://osf.io/wmbg8/>.

## **Results**

### **Descriptive Results**

#### ***Household SES***

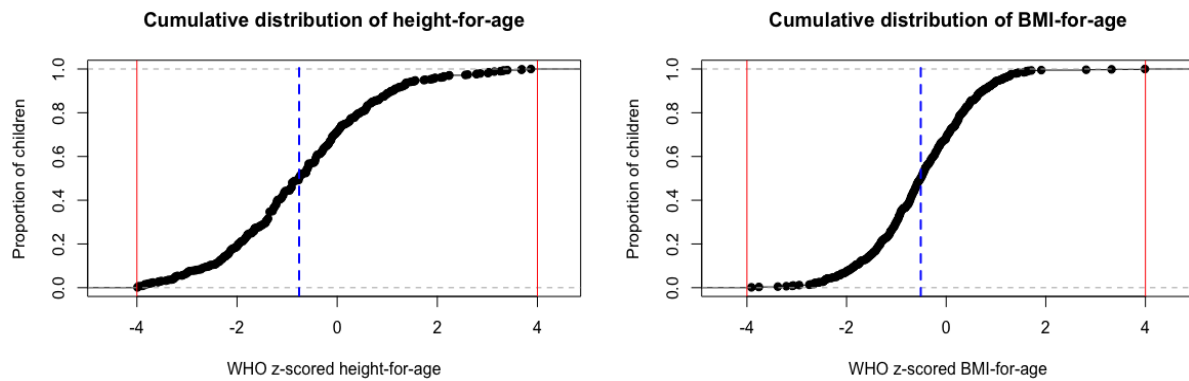
Family SES obtained from household inventory ranged from 0 to 14 (M=5.75, SD=2.74), see Table 1. Frequencies for each household item are reported in Figure 2. Although most children reported having electricity and a telephone at home (83% and 85%, respectively), very few had internet connections (6%). Radio and television were more common media (56% and 54%, respectively), and books were less common (children's books: 28%, adults' books: 28%), despite 92% of children reporting that a literate adult lived in their home.



*Figure 2.* Household SES Characteristics. Participants reported whether or not they had each of these fifteen items at home. Participants' SES (ranging from 0-15) is estimated from the sum of items.

### ***Child Anthropometry***

According to the World Health Organization's z-scored height-for-age (zhfa) index (2008), 18.6% of children in the present sample were stunted ( $z\text{-score} < -2$ ), 6.6% of whom were severe cases ( $z\text{-score} < -3$ ; Figure 3, left panel). According to the z-scored BMI-for-age (zbfa) index, 7.3% of the children were considered wasted ( $z\text{-score} < -2$ ), 1.0% of whom were extremely wasted ( $z\text{-score} < -3$ ) (Figure 3, right panel).



*Figure 3.* Physical development indicators, z-scored height-for-age and BMI-for-age, presented as cumulative distribution functions (i.e., proportion of children at or below a given z-score). Median scores are represented by dashed blue lines. The 4 SD thresholds used for outliers are represented by solid red lines. [color]

### ***Family Literacy***

Table 1 shows descriptive statistics concerning family literacy, including the presence of literate adults in the home, whether the child owns a schoolbook, and whether the child reported receiving help with homework. Overall, most children reported at least one literate adult in the household (92%), receiving help with their homework (71%), and owning a schoolbook (e.g., book used for literacy instruction at school; 71%).

### ***Executive Functions and Literacy***

Table 1 presents children's performance on EF (inhibitory control and working memory) and literacy tasks (letter, word, and nonword reading) for the total sample ( $n=630$ ) by grade level and gender. Results on the inhibitory control task were overall high, and scores increased by grade ( $r(610)=0.397$ ,  $p<0.001$ ). The working memory scores also showed the same pattern, with an increase related to grade ( $r(610)=0.574$ ,  $p<0.001$ ). Results of the three literacy tasks (Letter:  $r(625)=0.532$ ,  $p<0.001$ ; Word:  $r(625)=0.463$ ,  $p<0.001$ ; and Nonword reading:  $r(626)=0.418$ ,

$p < 0.001$ ) show the same grade-related increase, but with very low overall scores. Even in 5th grade, the average letter reading score was only 41%. Scores were even lower for reading words and nonwords, at 20% and 15%, respectively. There were no significant differences by gender on the working memory task ( $t(610) = -1.103$ ,  $p = .270$ ), or any of the literacy measures (Letter:  $t(624.95) = -0.608$ ,  $p = 0.54$ ; Word:  $t(623.57) = -0.11$ ,  $p = 0.91$ ; Nonword:  $t(624,42) = -0.30$ ,  $p = 0.76$ ), however, boys showed better performance on the inhibitory control task relative to girls ( $t(533.75) = -2.157$ ,  $p = 0.031$ ).

Table 1. Descriptive statistics

<b>Indicator</b>	<b>Full Sample Mean (SD)</b>	<b>Grade 1 Mean (SD)</b>	<b>Grade 3 Mean (SD)</b>	<b>Grade 5 Mean (SD)</b>
Age (6-14)	9.56(2.07)	6.83(1.06)	9.2(1.32)	11.26(1.3)
SES (0-15)	5.75(2.74)	5.77(2.77)	6.02(2.76)	5.47(2.69)
<b>Home Learning Environment</b>				
Literate Parent (% yes)	0.92(0.27)	0.87(0.34)	0.92(0.27)	0.94(0.23)
Homework Help (% yes)	0.71(0.45)	0.7(0.46)	0.75(0.43)	0.67(0.47)
Owens schoolbook (% yes)	0.71(0.45)	0.5(0.5)	0.72(0.45)	0.8(0.4)
<b>Physical Development</b>				
Height-for-Age (z score)	-0.72(1.47)	-0.48(1.66)	-0.78(1.39)	-0.77(1.39)
Stunted (% >2SD below)	0.19(0.39)	0.15(0.36)	0.21(0.41)	0.18(0.38)
BMI-for-Age (z score)	-0.51(1.02)	-0.26(1.06)	-0.5(1.01)	-0.62(0.99)
Wasted (% >2SD below)	0.07(0.26)	0.05(0.21)	0.08(0.28)	0.07(0.26)
<b>Executive Functions</b>				
Inhibitory Control (0-10)	8.99(2.21)	7.35(3.2)	8.97(2.12)	9.81(0.81)
Working Memory (0-14)	4.22(2.58)	1.54(1.93)	4.05(2.27)	5.66(2.02)

**Literacy (% of children with zero scores)**

Letter Reading (0-100)	27.72(24.33)	6.2(12.22)	24.8(21.36)	41.22(23.02)
% zero score	16.35%	47.58%	11.37%	5.88%
Word Reading (0-50)	11.98(14.67)	2.35(7.26)	8.84(11.49)	19.87(16.18)
% zero score	31.11%	75.81%	29.02%	10.98%
Nonword Reading (0-50)	8.82(12.09)	1.62(5.14)	6.54(9.75)	14.65(13.87)
% zero score	36.83	77.42%	39.22%	14.12%
N	630	124	255	251

**Bivariate Correlations**

We tested the direct bivariate correlations between all variables, reported in Table 2.

Table 2

*Means, standard deviations, and correlations with confidence intervals*

Variable	<i>M</i>	<i>SD</i>	1	2	3	4	5	6	7
1. SES	5.75	2.74							
2. Homework Help	0.71	0.45	.22** [.14, .29]						
3. Literate Parent	0.92	0.27	.20** [.13, .28]	.24** [.16, .31]					
4. Owns schoolbook	0.71	0.45	.07 [-.01, .15]	.06 [-.02, .14]	.08 [-.00, .16]				
5. Height-for-Age	-0.67	1.80	-.00 [-.08, .08]	-.00 [-.08, .08]	.06 [-.02, .13]	-.03 [-.11, .05]			
6. BMI-for-Age	-0.47	1.32	.01 [-.07, .09]	.07 [-.01, .15]	.06 [-.02, .14]	.03 [-.05, .11]	.21** [.13, .28]		
7. Inhibitory Control	8.99	2.21	.06 [-.02, .14]	.07 [-.01, .15]	.16** [.08, .24]	.17** [.10, .25]	-.01 [-.09, .07]	-.06 [-.14, .02]	
8. Working Memory	4.22	2.58	.09* [.01, .17]	.05 [-.03, .13]	.16** [.08, .24]	.18** [.10, .25]	-.09* [-.17, -.01]	-.07 [-.15, .01]	.38** [.30, .46]

			[.01, .16]	[-.02, .13]	[.08, .24]	[.10, .25]	[-.17, -.01]	[-.15, .01]	[.31, .45]
9. Letter Reading	27.72	24.33	.08 [-.00, .15]	.07 [-.01, .14]	.14** [.06, .22]	.28** [.21, .35]	-.04 [-.12, .04]	-.06 [-.14, .02]	.29** [.22, .36]
10. Word Reading	11.98	14.67	.06 [-.02, .13]	.06 [-.02, .13]	.12** [.04, .20]	.23** [.16, .31]	-.04 [-.11, .04]	-.06 [-.13, .02]	.24** [.16, .31]
11. Nonword Reading	8.82	12.09	.03 [-.04, .11]	.05 [-.03, .13]	.11** [.03, .19]	.21** [.13, .28]	-.01 [-.09, .07]	-.04 [-.11, .04]	.21** [.13, .28]

*Note.* *M* and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). \* indicates  $p < .05$ . \*\* indicates  $p < .01$ .

### Structural Equation Model: Impact of Physical Development and Home Learning

#### Environment on EF and Literacy

Overall, diagnostics for the model fit were good, with the exception of the uncorrected chi-squared test. However, when applying the Satorra-Bentler scaling correction, the chi-squared test of model fit met criterion ( $p > .05$ ). We also looked at several other metrics of model fit that are appropriate for large samples. The RMSEA and Standardized RMR metrics both met the less than 0.08 criterion. The robust CFI, NFI, and NNFI metrics met the greater than or equal to 0.95 criterion. Model fit tests, described in Table 3 generally supported acceptance of the model.

**Table 3.** Model fit diagnostics (see Hooper et al., 2008 for criteria).

Metric of Model Fit	Statistic	Criterion
Robust Chi-Squared ( $df=40$ )	67.409, $p=0.004$	$p > 0.05$
Chi-Squared with Satorra-Bentler scaling correction factor	$p=.558$	
Robust Root Mean Square Error of Approximation	90% CI: 0.015, 0.037	$< 0.08$
Robust Standardized Root Mean Square	0.027	$< 0.08$

**Incremental fit indices**

Robust Comparative Fit Index (CFI)	0.991	$\geq 0.90$
Normed Fit Index (NFI)	0.979	$\geq 0.95$
Robust Non-Normed Fit Index (NNFI)	0.986	$\geq 0.95$

The measurement model estimated the four latent variables (home learning environment, physical development, EF, and literacy) from their contributing measures. As depicted in Figure 4, all of the included measures significantly contributed to the latent variable estimates and were retained for the structural model.

In the SEM (see Figure 4 for illustration), SES was a significant predictor of the home learning environment ( $\beta=0.408$ ,  $p<0.001$ ) but not a significant predictor of physical development ( $\beta=-0.070$ ,  $p=.367$ ). SES was also not a direct significant predictor of EF ( $\beta=-0.028$ ,  $p=.722$ ) or literacy ( $\beta=-0.056$ ,  $p=.253$ ). The home learning environment ( $\beta=0.289$ ,  $p=0.036$ ), physical development ( $\beta=0.365$ ,  $p=0.034$ ), owning a schoolbook ( $\beta=0.162$ ,  $p=.003$ ), and age ( $\beta=0.752$ ,  $p<0.001$ ) were significant predictors of EF. The SEM revealed a significant indirect effect of SES on EF mediated by the home learning environment ( $\beta=0.118$ ,  $p=0.035$ ) but not mediated by physical development ( $\beta=0.025$ ,  $p=0.411$ ). EF was the largest predictor of literacy ( $\beta=0.489$ ,  $p<.001$ ), and owning a schoolbook ( $\beta=0.149$ ,  $p<.001$ ) also predicted literacy. The indirect effect of SES on literacy via EF was not significant ( $p=.718$ ), indicating that this relation could not bypass the mediation via home learning environment to explain literacy. See Table 4 for indirect effects.

Lastly, age was a significant and negative predictor of physical development ( $\beta=-0.497$ ,  $p<0.001$ ). This suggests that children's age-normed physical development decrease as they get older. We re-examined this relation by calculating the correlation coefficients between age with

z-scored height-for-age and age with z-scored BMI-for-age, separately from the rest of the model. Indeed these were significantly correlated (height-for-age:  $r(589)=-0.256, p<0.001$ ; BMI-for-age:  $r(589)=-.196, p<0.001$ ). In other words, these children fell—on average—another full standard deviation behind global norms every four years for height and every five years for BMI.

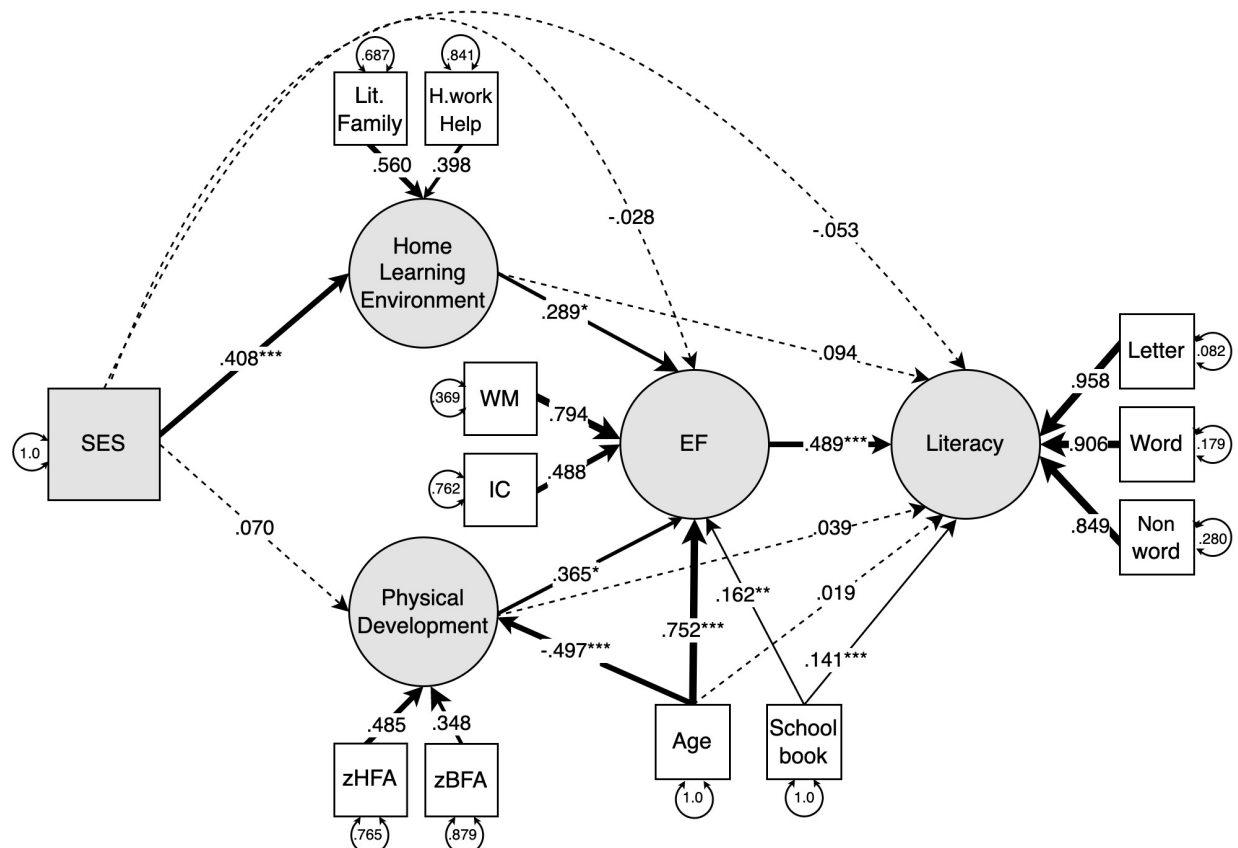


Figure 4. Visualization of the structural equation modeling results. Squares indicate manifest variables, and circles indicate latent variables. Arrow weight approximates the magnitude of the directed connection. Dotted arrows were tested in the model and found not statistically significant.

Table 4. Results of structural equation modeling for indirect effects

Structural Model			
Path	Effect	Std. $\beta$	$p$

SES-EF	Indirect Effect via Physical Development	0.025	0.411
	Indirect Effect via Home Learning Environment	0.118	0.035
	Total Effect	0.116	0.022
SES-Literacy	Indirect Effect via EF	-0.014	0.718
	Total Effect	-0.070	0.246

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### Discussion

This study aimed to increase our understanding of the relation between SES, EF, and literacy development in an understudied context: rural Côte d'Ivoire. Previous research has demonstrated the negative impacts of low-SES environments on children's EF and negative impacts on children's learning outcomes, including literacy. Although recent studies have started to examine how socioeconomic disadvantage affects EF of children growing up in LMICs (Obradović, Yousafzai, et al., 2016), an overwhelming majority of the research examining the relation between SES, EF, and literacy has been limited to western, educated, industrialized, rich, democratic (W.E.I.R.D.) contexts or high-income countries (i.e., HICs).

Given both the critical contributions of EF to literacy and the vulnerability of EF to socioeconomically disadvantaged environments, we asked how do context-appropriate SES-related factors influence EF development and literacy outcomes in primary-school-aged children in rural Côte d'Ivoire? We tested specific hypotheses concerning the mechanisms by which SES affects EF and literacy skills. We hypothesized that the relation between SES and literacy is mediated by EF and that distinct components of a child's environment, the home learning

environment and children's physical development, contribute to children's EF skills and in turn literacy.

The results of a structural equation model (SEM) provided evidence in support of our hypothesis. We found that EF mediated the relation between SES and literacy and corroborated previous results from other regions (Corso et al., 2016; Dias et al., 2011; Nesbitt et al., 2013; Sarsour et al., 2011). Moreover, this effect was a full, rather than partial, mediation. We did not find evidence that SES affects literacy directly, but only through an indirect effect mediated by EF. Previous studies have reported both direct effects of SES on literacy and indirect effects partially mediated by EF (Dilworth-Bart, 2012; Lawson & Farah, 2017), while others have also found indirect effects of SES on literacy, fully mediated by EF (Korucu et al., 2020; Nesbitt et al., 2013). These differences in results with respect to partial and full mediation may be attributed to the variables included in each respective model. Here, we examined the association between SES and literacy mediated by the home learning environment as well as EF. Beyond the indirect effects of SES on literacy observed here, SES may also be directly linked to literacy; e.g., higher SES is likely associated with a parent's ability to send their child to school (i.e., pay school enrollment fees, not depend on child labor as an income source, allowing the child to attend school regularly).

Notably, the SEM also demonstrated the importance of understanding the complexities of the rural Ivorian setting, including children's physical development and home learning environment. Growing up in socioeconomically advantaged environments increases the amount and quality of important, stimulating experiences essential for children's development (Obradović, Yousafzai, et al., 2016). Indeed, in support of our hypothesis, our SEM results

demonstrate independent contributions of both children's physical development and home learning environment to EF development.

Interestingly, the relation between children's physical development and EF was as robust as the relation between the home learning environment and EF, suggesting a crucial biological component in EF development. Albeit, it is important to note that home learning environments could be considered biological components of EF development as well given that home learning environments may reflect parental EF, and EF is a genetically influenced trait (Friedman et al., 2008). Specifically, we found that approximately 18.6% of children were stunted (low height-for-age), and 7.3% of children were considered wasted (low BMI-for-age). We also found that many children reported poor home learning environments (e.g., 29% of children did not receive any help with their homework and 8% of children reported living in a household without a single literate family member). We observed that EF was positively affected both by children's physical development (as indexed by height and BMI for age) and the home learning environment (having a literate parent, receiving help with homework). Children with adequate nutrition and protection from disease and illness and who receive quality care, stimulation, and educational scaffolding at home have the best chances of healthy brain development to support EF skills (Strupp & Levitsky, 1995).

Child age was also positively associated with EF skills. However, age was *negatively* associated with children's normative physical development, indicating that nutritional deficits (stunting, wasting) accrue over time and limit EF development. This suggests that poor nutrition experienced in early life, i.e., during a child's first 1000 days when nutritional deprivation has the greatest effects (Martorell, 2017), may persist into childhood as low height and weight. Lastly, while SES was significantly associated with the home learning environment, we did not

observe a significant relation between SES and children's physical development. This is perhaps surprising given the well-established links between SES and children's physical development (e.g. Noble et al., 2005). However, because the effects of poor nutrition compound over development (as indicated by the strong negative relation between age and physical development), that is, older children are more stunted than younger children given that the effect of poor nutritional accrue over time. The large variation in physical development (z-height-for-age coefficient of variation is 2.683) attributed to age observed here may obscure any significant effects between SES and physical development.

### **Implications**

This study provides new information regarding the relation between SES, EF, and literacy. Our analysis found a full mediating effect of EF skills between SES and literacy development. Notably, the home learning environment and children's physical development had distinct effects on children's EF. Our findings highlight the importance of EF skills in literacy development, particularly in contexts where children experience a higher risk of illiteracy, such as in rural Côte d'Ivoire, and indicate that EF skills may be differentially vulnerable to distinct poverty-related factors.

The results add to our understanding of the theoretical mechanisms that link SES with cognitive development and learning outcomes. That both physical development and home learning environments contributed to EF development is in line with a view that socioeconomic disadvantage is associated with EF through multiple physiological pathways. Malnutrition, which undermines children's physical development, may impact EF through multiple physiological mechanism that implicate the activity of the HPAA, including secreted cortisol levels, glucocorticoid receptor activity, and inflammation, which is linked with cortisol

dysfunction. Similarly, low SES home learning environments have been linked to increased cortisol levels, which can undermine the maturation and function of brain regions known to support EF.

By addressing the nutritional and environmental needs of children in their homes, we could positively affect the development of EF skills and improve literacy outcomes. Nutritional interventions such as school meal programs can support healthy physical growth, which in turn supports EF. For example, a longitudinal cluster randomized trial in Ghana found that school feeding programs improved height-for-age in 5-8 year old children, particularly children in living in households below the poverty line (Gelli et al., 2019). School meal interventions in early primary school years can have important benefits for cognitive development and learning; after 2 years, Ghana's school feeding program led to increased literacy and math standardized scores (Aurino et al., 2020). By addressing poverty directly, we might mitigate the indirect adverse effects of poverty on academic achievement. Large-scale poverty reduction programs such as cash transfers that address the nutritional and environmental needs of children (Gilligan & Roy, 2016) may indirectly support EF development, and in turn, literacy and other academic skills.

Interventions to support children's EF development directly have the potential to positively impact literacy outcomes. Some evidence suggests that the malleability of EF in childhood, which makes EF vulnerable to the adverse effects of poverty, can also be used to improve EF through intervention (e.g. Diamond & Lee, 2011). For example, an EF intervention (i.e., Tools of the Mind; Bodrova & Leong, 2007) has been shown to improve young children's overall EF (Barnett et al., 2006; Diamond et al., 2007; Mackey et al., 2011).

### **Limitations and Future Directions**

The present results add to our understanding of the mechanisms that link socioeconomically disadvantaged environments to children's EF skills and academic outcomes. Here, we examined children's inhibitory control and working memory, but other aspects of EF, such as cognitive flexibility (not assessed in the current study), may also predict literacy outcomes and be differentially sensitive to environmental factors. Moreover, our inhibitory control measure showed ceiling effects, which may be attributed to the paper-based and untimed adaptation of this task insofar as children had time to formulate a correct response. Additional research with more sensitive measures of inhibitory control may be beneficial. A critical limitation of the current research is the context of our study; crucially, all of our participants were growing up in impoverished rural communities. The extent to which our findings may generalize to urban poverty may be limited. There are significant qualitative differences between rural and urban impoverished communities; for example, the average family size may be smaller in urban areas than in rural areas. Additionally, children in urban areas may be exposed to higher rates of crime (Wells & Weisheit, 2004), which has also been shown to affect children's developmental outcomes (Schwartz & Gorman, 2003).

### **Conclusion**

SES has long been associated with disparities in academic achievement. Higher SES increases the likelihood that a child's developmental environment will support cognitive development through adequate nutrition and emotional/cognitive adult support. This study examined the relation between SES (as measured by a child's home environment), EF (neurocognitive skills which are vulnerable to environmental influence), and literacy. Crucially, our analysis incorporated measures of SES that aimed to capture the complex and

multidimensional aspects of SES in LMICs. We found that EF mediates the relation between SES and literacy and that the child's home learning environment and physical development have distinct effects on EF. Not only is EF an essential predictor of literacy, but, as we have demonstrated, the particular components of a child's environment (quality home learning environment, adequate nutrition for physical development) uniquely contribute to EF development and, by extension, literacy. The presence and severity of these factors differ significantly in LMICs compared to HICs. Research conducted exclusively in HICs would likely miss this nuance. Therefore, it is vital to consider the larger social and economic contexts in which child development research takes place and make every effort to include such understudied contexts in the study of child development.

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