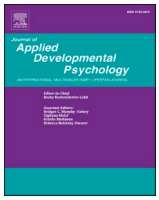
Journal of Applied Developmental Psychology 81 (2022) 101437

Contents lists available at ScienceDirect

Journal of Applied Developmental Psychology

journal homepage: www.elsevier.com/locate/jappdp



Directly assessed and adult-reported executive functions: Associations with academic skills in Ghana

Ishita Ahmed [a,*], Lily Steyer [a], Noelle M. Suntheimer [b], Sharon Wolf [b], Jelena Obradović [a]

[a] Graduate School of Education, Stanford University, USA
[b] Graduate School of Education, University of Pennsylvania, USA

ARTICLE INFO

Keywords:
Executive function
Academic skills
Direct assessment
Adult reports
Middle childhood
Sub-Saharan Africa

ABSTRACT

Extant work on the importance of children's executive function (EF) for academic skills typically employs either direct assessments of EF skills or adult reports of children's EF behaviors. Each approach has advantages, yet few studies have examined how different EF measurement approaches distinctly relate to child outcomes. We examined how direct assessment of EF skills and teacher- and assessor-reports of EF behaviors uniquely predicted literacy and numeracy skills in the Greater Accra region of Ghana ($N = 371$, average age = 9.3 years). All three EF measures demonstrated significant associations with children's concurrent numeracy and literacy performance. Controlling for previous academic skills, direct assessment of EF skills predicted numeracy, teacher-report of EF behaviors predicted literacy, and assessor-report predicted both. Adapted EF measures uniquely contribute to students' academic skills in a context where educational experiences tend to be teacher-directed and emphasize obedience, suggesting that promoting EF can support learning in Ghana.

Executive function (EF) skills and EF behaviors have been established as important predictors of academic skills in middle childhood. Extant evidence linking EF skills and EF behaviors to academic skills in middle childhood largely comes from high-income countries (HICs) and in particular, from the United States (U.S.; Cortés Pascual, Moyano Muñoz, & Quílez Robres, 2019; Jacob & Parkinson, 2015). In low- and middle-income countries (LMICs), by contrast, most investigations to date have examined associations between direct assessment of EF skills and academic skills in early childhood (e.g., Willoughby, Piper, Oyanga, & King, 2019). Limited research explores the contribution of adult-reported EF behaviors to academic skills in early or middle childhood. Teacher- and assessor-reports of EF behaviors in LMICs may reflect more cultural insight into how EF manifests in different educational settings. As such, the current study examines whether and how the direct assessment of EF skills and teacher- and assessor-reports of EF behaviors contribute to academic skills among Ghanaian third- and fourth-grade children. Specifically, we will examine the predictive validity of three different EF measures on academic outcomes in peri-urban Ghana, where cultural and socialization processes differ from those in HICs. Our research will shed light on the relevance of different aspects of EF development for learning in an understudied middle childhood context.

EF and academic skills

EF represents a set of higher-order cognitive processes that support self-regulation and engagement in goal-directed behavior (Diamond, 2013). In a recent review, Obradović and Willoughby (2019) posit that EF skills can be considered universal across contexts, yet how children access and apply these higher-order cognitive processes may vary by culture and context. EF *skills* encompass children's cognitive flexibility, inhibitory control, and working memory, which are directly assessed through children's performance on standardized tasks. EF *behaviors* are the application of EF skills in everyday contexts and researchers measure such behaviors via observation and ratings of children's abilities to pay attention, stay engaged, and inhibit impulses. Different measures of children's EF skills and EF behaviors capture related yet distinct aspects of EF because of different cognitive, behavioral, and contextual demands (Toplak, West, & Stanovich, 2013). However, past scholarship has rarely examined these measures in tandem to study their unique contributions to children's learning.

In LMICs, studies have linked EF skills to academic skills in early childhood across diverse settings (Lan, Legare, Ponitz, Li, & Morrison, 2011; von Suchodoletz, Uka, & Larsen, 2015; Willoughby et al., 2019; Wolf & McCoy, 2019). However, EF development continues throughout

* Corresponding author at: Stanford University Graduate School of Education, 485 Lasuen Mall, Stanford, CA 94305, USA.
E-mail address: iahmed2@stanford.edu (I. Ahmed).

https://doi.org/10.1016/j.appdev.2022.101437
Received 9 December 2021; Received in revised form 8 June 2022; Accepted 10 June 2022
Available online 21 June 2022

middle childhood and beyond (Best, Miller, & Naglieri, 2011; Spiegel, Goodrich, Morris, Osborne, & Lonigan, 2021) during a developmental period when children experience increasingly complex environmental and attentional demands and receive progressively less support from adults. As children age, they must independently apply EF skills to pay attention to and remember directions, finish their assignments, and work with peers on group activities (Finch, Garcia, Sulik, & Obradović, 2019). While evidence from HICs has demonstrated that EF skills and EF behaviors continue to influence academic skills for children ages 6 to 12 years old, little extant work has explored EF in middle childhood in LMIC settings.

Primary school classrooms in Ghana are teacher-directed with limited student participation, generally focus on memorization and repetition, and are centered around norms of obedience and collective efficacy (Agbenyega, 2018; Haslam, Mejia, Thomson, & Betancourt, 2019; Opoku-Amankwa, 2009). These prevalent classroom expectations and norms can influence the opportunities to apply EF skills and how EF behaviors are socialized. For example, children may receive more direct instructions from teachers on how to complete assignments and have fewer opportunities to independently apply EF skills. Overcrowded classrooms may also require greater attentional demands in Ghana, and children may need to apply their EF skills to complete their school assignments. Classroom norms of compliance and limited student participation can further shape the relevance of EF behaviors for learning and peer interactions. Analyzing different EF measures in the Ghanaian context can demonstrate how EF is applied in understudied educational settings to contribute to academic skills.

EF skills

EF skills include the ability to switch between different task rules and competing demands (cognitive flexibility), suppress goal-irrelevant responses (inhibitory control), and hold information in mind while performing operations on it (working memory; Diamond, 2013). EF skills support children's acquisition of literacy and numeracy capabilities (Spiegel et al., 2021). Specifically, reading requires children to switch between interpretations of word sounds and meanings, ignore irrelevant information to understand the correct meaning, and keep in mind what they are reading and update it (Blair & Raver, 2015). Children also flexibly shift attention among operations, inhibit inappropriate problem-solving strategies and irrelevant information, and remember and update information in the process of solving math problems (Allan, Hume, Allan, Farrington, & Lonigan, 2014; Blair & Raver, 2015; Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013). Studying EF skills can help explain how children use basic cognitive processes to support their academic learning.

Direct assessment of EF skills

Direct assessments provide a standardized and conceptually precise measure of children's EF skills (McCoy, 2019). Direct assessments are also relatively quick to administer, and many assessments have a rigorous psychometric evidence base (Zelazo, Blair, & Willoughby, 2016). Research has linked performance on EF tasks to neurobiological foundations and has revealed positive associations of EF with child academic outcomes in HICs and LMICs, which suggests the contribution of EF skills to academic skills may be comparable across contexts (Diamond, 2013; Obradović & Willoughby, 2019).

In the U.S., EF skills have been shown to predict math- and literacy-related growth in kindergarten when controlling for preschool EF skills and academic skills (Fuhs, Nesbitt, Farran, & Dong, 2014; Schmitt, Geldhof, Purpura, Duncan, & McClelland, 2017). Cross-sectional and longitudinal studies conducted in middle childhood have also demonstrated contributions of EF skills to academic skills (e.g., Ahmed, Tang, Waters, & Davis-Kean, 2019; Morgan et al., 2019; Sulik & Obradović, 2018).

In LMICs, including Sub-Saharan Africa, scholars have typically employed direct assessments of EF skills in early childhood to examine associations with academic skills. Among preschoolers in Pakistan, research has linked EF skills to general cognitive and language skills (Obradović, Yousafzai, Finch, & Rasheed, 2016). Studies have documented that EF skills contribute to both literacy- and numeracy-related outcomes (Lan et al., 2011; von Suchodoletz et al., 2015; Willoughby et al., 2019; Wolf & McCoy, 2019). Specifically, among a sample of 1409 children in Kenya, researchers found significant concurrent associations among EF skills and pre-literacy and pre-numeracy in early childhood (Willoughby et al., 2019). Further, in China and Kosovo, EF skills were concurrently related to math and reading achievement in smaller samples of 100 to 200 preschoolers (Lan et al., 2011; von Suchodoletz et al., 2015). Finally, a longitudinal study in Ghana—from which the current study draws its sample—found that EF skills were linked with changes in literacy and numeracy skills in early childhood (Wolf & McCoy, 2019). These studies attest to the relevance of directly assessed EF skills for academic skills among young children in LMICs. It is now important to extend this work to middle childhood, a period when children continue to develop EF skills, and control for previous levels of academic skills to isolate the association of EF measures with later academic skills.

EF behaviors

EF *behaviors* complement EF skills and include how children pay attention, stay on task, sustain concentration, follow directions, and work well by themselves and in groups. EF skills and EF behaviors can differ, as children's cognitive EF skills may manifest differently in everyday learning settings. EF behaviors help children stay engaged, control impulses, ignore environmental distractions, and collaborate effectively to persist on academic tasks. Different EF behaviors may be relevant for literacy and numeracy skills based on the task and the context in which children perform the academic task.

Teachers, who observe children in everyday contexts, and independent assessors, who observe children during standardized assessments, can rate children's EF behaviors. Ratings of EF behaviors may better reflect cultural expectations when compared to direct assessment of EF skills (Obradović & Willoughby, 2019), particularly as teachers report on how children apply EF skills within classroom contexts where cultural norms manifest. For example, obedience and social responsibility may be emphasized in LMICs, in contrast to HICs that prioritize individual autonomy (Jukes et al., 2021). Children may comply more with teacher's instructions when they are socialized in classrooms valuing obedience over individual autonomy, which can shape differences in the relevance of EF behaviors for learning across cultural contexts.

Teacher-report of EF behaviors

Researchers view teacher-report as a generalizable and ecologically valid EF behavior assessment, since teachers observe children's behavior across different situations and can report a perspective beyond a single task-based situation (McCoy, 2019; McKown, 2019; Toplak et al., 2013). Moreover, teachers have a reference group of same-age peers to inform their judgments of individual children's behavior (McKown, 2019).

Studies from the U.S. examining how teacher-report of EF behaviors relates to academic skills revealed positive concurrent and longitudinal associations with both literacy and numeracy in early childhood (e.g., Blair et al., 2015; Fuhs, Farran, & Nesbitt, 2015; Lonigan, Allan, & Phillips, 2017). Teacher-report of EF behaviors has also been linked to concurrent numeracy skills in middle childhood (Fuchs et al., 2006). Furthermore, one longitudinal study demonstrated that teacher-report of EF behaviors in kindergarten was significantly predictive of initial levels of literacy and growth in both literacy and numeracy from kindergarten to sixth grade (McClelland, Acock, & Morrison, 2006).

In LMICs, researchers have shown positive correlations between teacher-report of EF behaviors and academic achievement in Kenya

among a sample of 526 first grade students (average age = 7.8 years; Amukune & Jozsa, 2021). Other work has employed teacher-report among a small sample (N = 150) of preschool children in Kosovo, showing a positive concurrent association with numeracy skills, but not literacy skills (von Suchodoletz et al., 2015). Notably, this association was not statistically significant after accounting for direct assessment of EF skills and assessor-report of EF behaviors. Therefore, teacher-report of EF behaviors captured constructs that overlapped with the other EF measures and did not uniquely contribute to numeracy skills. We need additional research to understand whether teacher-report of EF behaviors has unique implications for academic skills in LMICs and should thus be utilized more broadly.

Assessor-report of EF behaviors

Assessors who engage with children during a direct assessment of EF or other types of standardized tests may also report information about children's EF behaviors during the assessment. Since independent assessors do not have a previous relationship with the child, assessor-report may capture children's EF behaviors with greater standardization than teacher-report (McCoy, 2019). Experienced assessors also benefit from a broad comparison group against which to rate children's behaviors, improving their ability to calibrate their scores and minimize reference bias (McCoy, 2019).

Researchers have found associations of assessor-report of EF behaviors with academic and pre-academic skills in preschool-aged children in the U.S. (e.g., Daneri, Sulik, Raver, & Morris, 2018). A study in the U.S. also found a positive association of assessor-report of EF behaviors with adaptive functioning, which included academic achievement, among low-income youth ages 8 to 18 years old (Buckner, Mezzacappa, & Beardslee, 2009). Yet, assessor-report is the least common of the three EF measures in HICs, and further research is needed to examine its contribution to academic skills, especially in middle childhood.

In LMICs, the most commonly used assessor-report measure has been the Preschool Self-Regulation Assessment Assessor Report (PSRA-AR), which has been validated for use with socioeconomically and racially/ethnically diverse children in HICs (Daneri et al., 2018). Cross-sectional studies utilizing the adapted versions of PSRA-AR alongside direct assessments of EF skills in early childhood have found positive associations of EF behaviors with both literacy and numeracy in Kenya and Kosovo (von Suchodoletz et al., 2015; Willoughby et al., 2019) and with pre-academic skills in Pakistan (Obradović, Finch, Connolly, Siyal, & Yousafzai, 2022). In these studies, researchers either composited EF skills and EF behaviors into a single predictor in Kenya (Willoughby et al., 2019) or tested them in separate models in Kosovo (von Suchodoletz et al., 2015). In rural Pakistan, researchers included direct assessment of EF skills and assessor-report of EF behaviors in the same model, finding that each measure uniquely predicted children's pre-academic skills (Obradović et al., 2022). When researchers included all three EF measures—direct assessment, teacher-report, and assessor-report—in the same model, assessor-report of EF behaviors did not contribute to preschoolers' academic skills in Kosovo (von Suchodoletz et al., 2015). No studies to date have examined how assessor-reported EF behaviors relate to academic skills over time or in middle childhood in LMICs.

Unique contribution of three different EF measurement approaches

When used in tandem, directly assessed and adult-reported measures of EF can offset one another's inherent limitations and offer a more comprehensive understanding of children's EF. For example, although direct assessments of EF skills have demonstrated utility across diverse contexts, they are not as ecologically valid as teacher- and assessor-reports because research teams typically conducted them in controlled environments using de-contextualized tasks rather than everyday activities (McCoy, 2019). Conversely, both teacher- and assessor-reports can be less conceptually precise than direct assessments because the adults administering them may struggle to distinguish EF behaviors from other child characteristics (McCoy, 2019).

Additionally, direct assessments and assessor-reports may not suffer from the same biases attributed to teacher-reports. Teachers may over-report positive behaviors and under-report negative behaviors due to social desirability bias (McCoy, 2019). Further, differences in teachers' classroom experiences and training can contribute to large variation in the reference groups they use when rating individual children's behavior, potentially further biasing their reports (Phillips & Lonigan, 2010). Assessors' lack of personal connections with children and potential broad exposure to a range of children's behaviors within the studied population may yield more standardized observational ratings than teacher reports (Heine, Lehman, Peng, & Greenholtz, 2002; McCoy, 2019). However, assessor training and ongoing supervision are critical to obtaining high quality data (Obradović & Willoughby, 2019).

Studies of children and adults in HICs utilizing direct assessments of EF skills and teacher- and assessor-reports of EF behaviors offer evidence that these measurements capture unique underlying constructs of EF that, although related, do not necessarily overlap (Toplak et al., 2013). Indeed, researchers have documented concurrent and longitudinal associations among measures of EF skills and EF behaviors and academic skills among preschool-aged children in HICs (e.g., Birgisdóttir, Gestsdóttir, & Thorsdóttir, 2015; Blair et al., 2015; Fuhs et al., 2015; Gestsdottir et al., 2014; Lonigan et al., 2017; Schmitt, Pratt, & McClelland, 2014). A cross-sectional study of 247 preschool children including all three types of EF measures found associations of both direct assessment of EF skills and teacher-report of EF behaviors with numeracy and literacy (Schmitt et al., 2014). Further, concurrent and longitudinal studies in HICs that include both direct assessment of EF skills and teacher-report EF behaviors show unique contributions to academic skills in middle childhood (Dekker, Ziermans, Spruijt, & Swaab, 2017; Finders, McClelland, Geldhof, Rothwell, & Hatfield, 2021; Gerst, Cirino, Fletcher, & Yoshida, 2017; Lenes, McClelland, ten Braak, Idsøe, & Størksen, 2020; Morgan et al., 2019).

In LMICs, the only studies that incorporated multiple EF measures were conducted in early childhood (Obradović et al., 2022; von Suchodoletz et al., 2015; Willoughby et al., 2019). Researchers found positive associations between a composite EF measure including direct assessment of EF skills and assessor-report of EF behaviors and academic skills in Kenya (Willoughby et al., 2019). Both direct assessment of EF skills and assessor-report of EF behaviors uniquely contributed to pre-academic skills in Pakistan (Obradović et al., 2022). Examining the unique contributions of all three EF measures demonstrated that only direct assessment of EF skills was relevant for concurrent academic skills in Kosovo (von Suchodoletz et al., 2015). Whether this association exists over time and in other settings is unknown; further research using measures of previous academic skills can investigate possible unique contributions of each EF measure in predicting gains in numeracy and literacy and the implications for improving learning for primary school students in LMICs.

Primary schooling in Ghana

In this study, we extend the literature on the unique contributions of EF measures to academic skills in LMICs by examining these associations in Ghanaian primary school students. Ghana is a lower-middle-income country in West Africa with approximately 32.4 million people and a gross domestic product per capita of $5413. A majority of the population (76.6%) over age 15 can read and write, and 57.3% of the population lives in urban areas (Central Intelligence Agency, 2021).

The Ghanaian government provides free and compulsory primary school for all Ghanaian children starting at age six and for six years following kindergarten (Ghana Education Service, 2018a). In 2019, the majority of Ghanaian children of primary school age (86%) were enrolled in primary school, and classrooms had an average of 27

students per teacher (The World Bank, 2020a, 2020b). Although the primary school curriculum focuses on academic skill development in literacy, numeracy, and problem-solving skills (Kamran, Liang, & Trines, 2019), learning levels are very low (Angrist, Djankov, Goldberg, & Patrinos, 2021). For example, as of 2016, at the end of Primary 2, 80% of students could not read a single word and 70% could not correctly answer a basic subtraction problem (Ghana Education Service, RTI International, and Education Assessment and Research Centre, 2016). It is important to study EF measures in Ghanaian primary schools, where classroom experiences and expectations differ from those in HICs. Such work will allow us to understand if adapted measures of EF skills and EF behaviors are relevant for capturing learning outcomes in these environments.

Current study

This study aims to understand how direct assessment of EF skills and teacher- and assessor-reports of EF behaviors uniquely contributes to literacy and numeracy skills among third- and fourth-grade students in Ghana. We hypothesized that EF skills and EF behaviors would show unique positive associations with both literacy and numeracy in our middle childhood sample. We anticipated that the significance and magnitude of these linkages would vary by measurement type due to each measure's relative advantages and disadvantages in different learning contexts.

Our multi-method, multi-informant study design enabled us to examine the unique association of each measure with academic skills. Specifically, we used a tablet-based direct assessment of EF skills, a teacher-report of children's EF behaviors in the classroom, and an assessor-report of EF behaviors during administration of the direct assessment to construct three composite scores for each EF measurement modality. Our outcomes included standardized scores from international literacy and numeracy assessments conducted concurrently with the EF measures. We also tested lagged models that included measures for previous academic skills.

Our study took place in the Greater Accra region of Ghana, which includes the urban capital of Accra and surrounding peri-urban areas. The results of this study are relevant for similar Sub-Saharan African learning environments and provide a foundation for understanding the unique contributions of different EF measures to literacy and numeracy skills in LMIC settings.

Methods

Participants and procedures

Study participants came from the Quality Preschool for Ghana (QP4G) school-randomized controlled trial implemented in the 2015–2016 school year (Wolf, Aber, Behrman, & Tsinigo, 2019). The original QP4G sample comprised 3435 students (average age = 5.2 years) at baseline representative of six districts in the Greater Accra region and were subsequently followed for three additional waves. Due to limited resources, the current study draws on a random subsample of 407 students of the 2701 who had completed assessment data from the prior three survey years.

Children in the current study attended 216 schools across 14 districts in the Greater Accra region. On average, this subsample had similar baseline demographic characteristics and EF outcomes as the full QP4G sample; however, they had higher academic and social-emotional scores in year one of the study (see Appendix Table A1 for details). Data collection for the current study took place in November 2019. Six trained Ghanaian enumerators collected data primarily in the students' schools and were randomly assigned to students. The final analytic sample consists of 371 students who had adequate direct assessment EF data (described further below). In lagged models, we utilize academic achievement data collected one year earlier during the 2018 QP4G follow-up survey (Wolf, 2019).

Table 1 presents demographic statistics for all study variables. In 2019, children in the analytic sample were mostly in grades three (42%) and four (48%).[1] About half of the sample is female (49%) and the average age is 9.3 years. Most parents (82%) completed primary school. On average, students' households fall in the mid-range of household wealth in Ghana with a score of 63.64 (SD = 11.60) on the Ghana Poverty Scorecard (Schreiner & Woller, 2010), which is a measure of household asset-based wealth ranging from 0 to 100. Additionally, 48% of the students attended private school in the 2019 academic year.

Measures

Executive function skill direct assessment

The *Assessment of Motivation, Effort, and Self-Regulation (AMES)* is a tablet-based direct assessment battery that includes two EF tasks (Obradović, 2019). Researchers piloted AMES with primary schoolchildren in Ghana prior to data collection and ultimately adapted the length of time stimuli appeared on screen. Other scholars have previously used AMES in Côte d'Ivoire with 6- to 14-year-old children and adolescents, and similar tablet-based EF assessments have also been used in South Africa and Kenya, where they have demonstrated associations with learning outcomes (Cook et al., 2019; Willoughby et al., 2019). Nearly all AMES assessments took place at the child's school in a comfortable space away from the classroom, with the remaining children assessed at home. Assessors introduced the tablets to children during rapport building and let children become familiar with the tablets prior to the assessment.

Hearts and flowers task

The *Hearts and Flowers* task (H&F; Davidson, Amso, Anderson, & Diamond, 2006) measures inhibitory control (i.e., the ability to suppress dominant goal-irrelevant responses) and cognitive flexibility skills (i.e., the ability to switch between competing task rules) (Diamond, 2013). Other researchers also adapted the tablet-based H&F task in Zimbabwe and Kenya. There were four blocks: a block of 16 congruent 'hearts' trials, a block of 16 incongruent 'flowers' trials, and two blocks of 24 mixed 'heart and flower' trials. For congruent heart trials, students were instructed to press the button on the same side as the presented stimuli (i.e., heart). For incongruent flower trials, students were instructed to press the button the opposite side of the stimuli (i.e., flower), measuring inhibitory control. The stimuli for the hearts and flowers trials appeared on the screen for 1500 milliseconds. For mixed trials, students were presented with both heart and flower trials to assess cognitive flexibility. The stimuli for the mixed trials appeared on screen for 2000 milliseconds for slow blocks and 1500 milliseconds for fast blocks. The fast block was more challenging than the slow block because the stimuli appeared on the screen for less time.

We created the EF skills composite variable using accuracy scores based on the proportion of correct responses for the incongruent flowers trials (α = 0.94) and mixed trials (α = 0.95 for both trials). Accuracy scores include trials with and without a response (scored as incorrect). We averaged the scores from the two mixed trials blocks if the respondent had scores for both trials. If a respondent scored below 50% on any of the blocks, we set their accuracy score to 50% (probability of correctly responding by chance). This approach prevents outliers from strongly influencing the results.

We also calculated reaction time (RT) composites as the mean RT for correct H&F trials in each block and included the RT composites in supplementary analyses (see Results and Supplemental Appendix), as

[1] Sampling for the QP4G RCT took place over two grades. 26 students (7%) are in lower grades because of grade repetition and 10 students (3%) are in higher grades.

Table 1
Descriptive statistics for all study variables.

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1.	EF Direct Assessment Score	–													
2.	SCS Academic Skills Subscale	0.21***	–												
3.	PSRA Scale	0.49***	0.19***	–											
4.	2019 Numeracy Skills	0.46***	0.25***	0.37***	–										
5.	2019 Literacy Skills	0.37***	0.34***	0.33***	0.63***	–									
6.	2018 Numeracy Skills	0.47***	0.31***	0.28***	0.64***	0.62***	–								
7.	2018 Literacy Skills	0.35***	0.27***	0.30***	0.48***	0.69***	0.69***	–							
8.	Female	−0.04	0.10*	−0.03	0.06	0.12**	0.05	0.09	–						
9.	Age (years)	0.05	−0.19***	−0.04	0.02	−0.06	0.19***	−0.01	−0.05	–					
10.	Private school	0.17***	0.25***	0.13**	0.32***	0.35***	0.30***	0.25***	0.01	−0.32***	–				
11.	Poverty Scorecard	0.11*	0.24***	0.13**	0.15**	0.25***	0.16***	0.27***	−0.00	−0.31***	0.43***	–			
12.	Parent completed primary school	0.04	0.10	0.08	0.11*	0.14**	0.08	0.08	−0.04	−0.27***	0.21***	0.29***	–		
13.	TT Treatment	0.02	0.01	−0.01	0.04	0.04	0.03	0.02	−0.12**	−-0.02	0.10**	−0.01	−0.01	–	
14.	TTPA Treatment	0.05	0.01	0.00	−0.02	−0.04	−0.00	0.04	0.06	0.02	0.00	0.12**	−0.04	−0.53***	–
	N	371	344	371	371	371	371	371	371	371	371	267	261	371	371
	Mean	−0.00	3.65	3.64	0.71	0.53	0.48	0.54	0.49	9.29	0.48	63.64	0.82	0.35	0.34
	SD	(1.00)	(0.75)	(0.52)	(0.20)	(0.27)	(0.16)	(0.16)	(0.50)	(1.27)	(0.50)	(11.60)	(0.38)	(0.48)	(0.47)
	Min	−3.13	1.29	1.17	0.05	0.00	0.04	0.13	0.00	5.00	0.00	32.00	0.00	0.00	0.00
	Max	2.25	5.00	4.00	1.00	0.94	0.89	0.88	1.00	14.00	1.00	89.00	1.00	1.00	1.00

Note. Teacher-report of EF behaviors is the SCS Academic Skills Subscale; Assessor-report of EF behaviors is the PSRA Scale.
Poverty scorecard is a measure of household wealth with greater numbers indicating greater household wealth.
TT is an indicator that the child was assigned to the Teacher Training baseline treatment group;
TTPA is an indicator the child was assigned to the Teacher Training and Parental Awareness baseline treatment group.
* $p < .05$, ** $p < .01$, *** $p < .001$.

studies in the U.S. demonstrate that RT can be informative of children's EF skills in middle childhood (Camerota, Willoughby, & Blair, 2019).

Memory game task

The *Memory Game* task measures short-term memory (i.e., the ability to hold information over a short timeframe) and working memory (i.e., the ability to hold and update information while performing some operation on it) (Diamond, 2013). This visual working memory task does not rely on familiarity with numbers or words; thus, it does not confound EF with children's literacy or numeracy skill levels. The task involved two blocks: 'forward' and 'backward.' Students viewed a sequence of colored squares that lit up in an unpredictable pattern in a 3 × 3 grid. In the forward block, assessors instructed students to touch the squares in the order in which they lit up (short-term memory). In the backward block, assessors instructed students to touch the squares reversing the order in which they lit up (working memory). The sequences of squares became progressively longer—and thus increasingly difficult. There were three trials for each sequence length in the memory game task. Each block ended after three consecutive incorrect trials. For each block, we used the total number of correct answers.

EF skills composite

We created an EF composite variable by standardizing and averaging four scores: the flowers accuracy score, the mixed accuracy score, the forward memory number correct, and the backward memory number correct ($\alpha = 0.71$). Appendix Table A2 shows the descriptive statistics and correlations of the different components used for the EF composite variable. We required at least two scores per student to calculate the composite. Upon creation, we standardized the composite measure to have a mean of zero and a standard deviation of one. This composite EF approach aligns with other studies that aim to capture multiple skills (e.g., Miyake & Friedman, 2012).

Executive function behavior teacher-report

For teacher-report of EF behaviors, we piloted the Duke University Social Competence Score (Conduct Problems Prevention Research Group, 1990) to capture behaviors that were relevant in Ghana and adapted to the Ghanaian context to include explanations and synonyms for unfamiliar words. We previously used this adapted teacher-report measure to examine QP4G impacts (Wolf, 2019). The teacher-report included seven items that capture children's academic-related behavioral skills (e.g., "functions well even with distractions," "stays on task"). All seven items are listed in Appendix Table A3. Teachers rated each EF behavior on a five-point scale (*0 = Not at all, 1 = A little, 2 = Moderately well, 3 = Well, 4 = Very well)*, with higher scores indicating more developed EF behaviors. We created a composite score by taking the average of the scores across the items, and it showed high internal consistency ($\alpha = 0.85$).

Executive function behavior assessor-report

The Preschool Self-Regulation Assessment Assessor Report (PSRA-AR; Smith-Donald, Raver, Hayes, & Richardson, 2007) is an assessor-report that measures EF behavior, including children's self-regulation of emotion, attention, and behavior, with a rating scale that is linked to specific behavioral markers. We adapted this measure to the Ghanaian context by selecting items that were more relevant and ensuring that the wording was appropriate and clear for the assessors in this context. For example, we reversed the order of the response options from the original PSRA-AR to start with the option that reflected a lower level of a certain EF behavior and end with the option that reflected a higher level of that same EF behavior because that order was more familiar to the assessors. Other researchers have also used the PSRA-AR in Kenya, where it demonstrated correlations with early numeracy and literacy skills (Willoughby et al., 2019).

In this study, all assessors had previously administered the PSRA-AR in earlier follow-up studies for QP4G. Assessors reported each child's EF behavior immediately after the child's assessment. Field supervisors observed 11% of the assessments and reviewed the assessor's PSRA-AR ratings to confirm their accuracy. The items on the PSRA-AR describe what the behavior looks like and rely less on subjective measures of frequency or degree, which helps to ensure reliability. For example, assessors rated students on the item, "Pays attention to instructions and demonstration", on the following scale: *1 = Child spends most of the time off-task, inattentive; 2 = Child's attention frequently drifts and requires frequent prompts; 3 = Child's attention occasionally drifts, particularly at the end of activities, but is responsive to prompts; 4 = Child looks closely at pictures to distinguish between them. Child attends to and complies with the Child assessor*. For this analysis, we used six PSRA-AR items that measure EF behaviors and closely relate to the teacher-report items (e.g., "pays attention to instructions and demonstrations," "sustains concentration", "cooperates"). Appendix Table A4 lists the six items and the specific four-point scale on which each was scored, with higher scores indicating more developed EF behaviors. We created a composite score by taking the average of the six items, and it showed high internal consistency ($\alpha = 0.90$).

Academic skills

Literacy skills

The Early Grade Reading Assessment (EGRA; RTI International, 2015) is a collection of subtasks that measure the foundational skills needed for reading. It is used in early primary grades and was adapted to local languages and grade levels in Ghana. The 2019 literacy skills measure includes four EGRA subtasks: (1) letter-sound identification (measures letter-sound correspondence; $\alpha = 0.97$), (2) non-word decoding (ability to decode unfamiliar words; $\alpha = 0.97$), (3) oral reading fluency (ability to fluently read a short passage; $\alpha = 0.99$); and (4) reading comprehension (assess overall reading competence; $\alpha = 0.87$). We scored all subtasks binarily as correct or incorrect. We created a composite 2019 literacy score by averaging the percent of correct responses for each domain ($\alpha = 0.88$) and standardizing it for the analysis.

The 2018 literacy skills measure includes the same EGRA subtasks on letter-sound identification ($\alpha = 0.97$) and nonword decoding ($\alpha = 0.97$) as in 2019 and additional measures of expressive vocabulary ($\alpha = 0.42$) and listening comprehension ($\alpha = 0.68$). There is also a measure of phonological awareness ($\alpha = 0.66$) from the International Development and Early Learning Assessment (IDELA; Pisani, Borisova, & Dowd, 2018). We created a composite 2018 literacy score by averaging the percent of correct responses for each domain ($\alpha = 0.72$) and standardizing it for the analysis.

Numeracy skills

We employed the Early Grade Math Assessment (EGMA; RTI International, 2014) to assess children's early math skills in 2019. Like the EGRA, it is used in early primary grades and was adapted to local languages and grade levels in Ghana. The 2019 numeracy skills measure includes four EGMA subtasks: (1) quantity discrimination (ability to compare quantities; $\alpha = 0.84$), (2) missing number (completing number patterns; $\alpha = 0.79$), (3) addition—level 2 ($\alpha = 0.61$); and (4) subtraction—level 2 ($\alpha = 0.73$). We scored all subtasks binarily as correct or incorrect. We created a composite 2019 numeracy score by averaging the percent of correct responses for each domain ($\alpha = 0.69$) and standardizing it for the analysis.

The 2018 numeracy skills measure includes the same EGMA subtasks on quantity discrimination ($\alpha = 0.82$), missing number ($\alpha = 0.69$), addition ($\alpha = 0.89$), and subtraction ($\alpha = 0.88$) as in 2019 and additional measures of number identification ($\alpha = 0.91$) and word problems ($\alpha = 0.57$). We created a composite 2018 numeracy score by averaging the percent of correct responses for each domain ($\alpha = 0.86$) and standardizing it for the analysis.

Covariates

Parents reported child- and family-level demographic characteristics. These characteristics included child age and sex, a binary indicator of private school attendance, and a binary indicator of parental completion of primary schooling. We also included a measure of household wealth, which is based on multiple indicators such as household assets, employment of household head, and number of household members. We further included a binary indicator for the six baseline districts of the preschools that students were sampled from in the QP4G study.

Two baseline QP4G treatment-related covariates were also included. In the QP4G study, to examine the impact on early childhood education outcomes, researchers randomly assigned schools to three conditions: (1) teacher training; (2) teacher training plus parental-awareness meetings; or (3) a control group (Wolf et al., 2019). Our current sample includes students in each study condition. We included two binary indicators for whether the student was assigned to the teacher training or teacher training plus parental-awareness treatment. Treatment status is relevant given previously recorded differences in academic outcomes related to the early childhood education interventions received (e.g., Wolf, 2019).

Ongoing evaluation of data collection efforts revealed that 46 children assessed by one assessor scored lower on EF, on average, than the rest of the sample, despite a standard protocol that was to be followed. We included a dummy variable representing this assessor as an additional covariate to account for potential differences in the data. We also confirmed that excluding cases associated with this assessor does not alter our findings.

Missing data and analytic strategy

Technical complications during AMES administration led to missing data for 8.8% ($N = 36$) students, resulting in an analytic sample of 371 students from the 407 sampled. Among the analytic sample of 371 students with direct assessment EF skills data, 27 (7%) did not have teacher-reported EF behavior scores because their teachers did not fill out the questionnaire. Further, we lacked data on household wealth for 104 students (28%) and on parent education for 100 children (27%). We addressed missing data on these covariates using Full Information Maximum Likelihood, which extends maximum likelihood estimation and uses all possible data points in the analysis of structural equation models. This approach is regarded as one of the best ways to handle missing data (Enders, 2010).

We used path analysis in Mplus Version 7.4 to examine associations among EF skills and EF behaviors and academic outcomes. The cross-sectional model (Model 1) examined the independent relations among the three EF measures and concurrent literacy and numeracy skills. The lagged model (Model 2) examined these same relations while controlling for previous literacy and numeracy skills. Both models included demographic and treatment status covariates in addition to district fixed effects. Both models were fully saturated and included covariance between the 2019 literacy and numeracy outcomes. We clustered standard errors at the school level to account for the original RCT sampling frame.

Results

Descriptive statistics

Table 1 presents bivariate correlations among all study variables. We found positive associations between measures of EF skills and EF behaviors with each other (*rs* ranged from .19 to .49, *ps* < .001) and with 2019 and 2018 literacy and numeracy skills (*rs* ranged from .25 to .47, *ps* < .001). We also found positive correlations between literacy and numeracy skills (*rs* ranged from .63 to .69, *ps* < .001), a result that aligns with other studies that use academic assessments in middle childhood

(e.g., Morgan et al., 2019; Obradović, Sulik, Finch, & Tirado-Strayer, 2018). The correlation between these academic skills reflects the shared method between the two academic tests and the underlying construct of academic achievement. We further found associations of private school attendance and household wealth with higher performance across all the EF measures. We did not find significant links of inclusion in the teacher training and/or parental awareness interventions during QP4G with EF measures or academic outcomes.

Model 1: Cross-sectional associations

We present path analysis results in Table 2. Over and above the included covariates, the three EF measures increased R^2 by 18.4% (to 37.6%) for numeracy skills and by 17.6% (to 37.7%) for literacy skills. Model 1 demonstrated that all three EF measures had significant additive associations with children's concurrent numeracy and literacy performance. As illustrated in Fig. 1, we found positive associations of numeracy with direct assessment of EF skills ($\beta = 0.32$, $p = .000$), teacher report of EF behaviors ($\beta = 0.13$, $p = .023$), and assessor report of EF behaviors ($\beta = 0.25$, $p = .000$). We also found positive associations of literacy with direct assessment of EF skills ($\beta = 0.22$, $p = .000$), teacher report of EF behaviors ($\beta = 0.21$, $p = .000$), and assessor report of EF behaviors ($\beta = 0.28$, $p = .000$).

Model 2: Lagged cross-sectional associations

Model 2 revealed that controlling for previous levels of academic skills, which emerge as robust predictors of current academic skills, changes the predictive power of the three EF measures. Including the controls for previous academic skills increased the R^2 by 13.2% (to 50.8%) for numeracy skills and by 20.4% for literacy skills (to 58.1%). As illustrated in Fig. 2, direct assessment of EF skills continued to independently predict numeracy skills ($\beta = 0.14$, $p = .002$), but it did not predict literacy skills. In contrast, teacher-report of EF behaviors continued to independently predict literacy skills ($\beta = 0.10$, $p = .008$), but not numeracy skills. Assessor-report of EF behaviors remained a significant predictor of both domains, explaining both numeracy ($\beta = 0.14$, $p = .014$) and literacy ($\beta = 0.10$, $p = .034$).

Supplementary analysis

We also tested whether the RT composite from only the H&F task contributed to academic outcomes over and above the main EF skills accuracy composite and EF behaviors measures in our models. We did not include RT composite in the main models because EF skills are calculated as a separate composite and the Memory Game task did not include RT. RT uniquely predicted literacy skills in cross-sectional analyses. RT did not uniquely contribute to numeracy in the cross-sectional model or to either domain in the lagged model. We present our full results in the Supplemental Appendix.

Discussion

We offer the first investigation of the unique contributions of direct assessment of EF skills and teacher- and assessor-reports of EF behaviors to academic skills in middle childhood in a LMIC. Our findings suggest that all three EF assessments were relevant and uniquely contributed to concurrent academic skills in Ghanaian third- and fourth-graders, a developmental period characterized by EF growth. Further, the three EF measures differentially predicted literacy and numeracy in lagged models, suggesting varying relevance of each EF measure for each academic skill. Accounting for previous academic skills, only assessor-report of EF behaviors contributed to both literacy and numeracy. As such, assessor-report of EF behaviors may be a valid assessment to integrate during structured assessment protocols to measure foundational behaviors that support learning, particularly in contexts where cultural and classroom norms encourage compliant behavior, which may shape how different EF measures contribute to academic skills.

Associations among EF measures

Similar to the only other study in a LMIC to employ all three EF measures (von Suchodoletz et al., 2015), we found correlations among all three EF measures, which suggests that they may contribute to a common overarching EF construct. Yet at the same time, each measure was distinct. EF skills and EF behaviors may be expressed differently across contexts in response to varying expectations and goals within a

Table 2
Association among executive function measures and academic skills.

	Model 1: Cross-sectional associations						Model 2: Lagged associations					
	Numeracy			Literacy			Numeracy			Literacy		
Variable	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*	*B*	*SE*	*p*
Executive function measures												
Direct Assessment	0.315	0.049	.000	0.223	0.053	.000	0.144	0.046	.002	0.061	0.042	.144
Teacher-Report	0.128	0.056	.023	0.206	0.049	.000	0.017	0.046	.708	0.099	0.037	.008
Assessor-Report	0.246	0.063	.000	0.278	0.061	.000	0.142	0.058	.014	0.104	0.049	.034
2018 academic controls												
Numeracy							0.487	0.061	.000	0.195	0.057	.001
Literacy							0.006	0.062	.922	0.429	0.053	.000
Demographic controls												
Female	0.049	0.042	.245	0.077	0.040	.057	0.039	0.038	.303	0.055	0.034	.108
Age (in years)	0.118	0.050	.019	0.062	0.054	.248	−0.033	0.046	.474	−0.036	0.048	.449
Private School	0.198	0.048	.000	0.173	0.056	.002	0.090	0.047	.053	0.103	0.051	.042
Household Wealth	−0.005	0.061	.937	0.086	0.060	.745	−0.019	0.057	.743	−0.007	0.055	.900
Parent Completed Primary	0.075	0.057	.191	0.060	0.062	.332	0.038	0.048	.426	0.040	0.048	.408
Baseline treatment status												
Teacher training (TT)	−0.006	0.057	.923	−0.020	0.060	.745	0.000	0.046	.992	−0.026	0.041	.517
TT and parental awareness (TTPA)	−0.047	0.056	.406	−0.083	0.055	.130	−0.031	0.047	.504	−0.083	0.040	.039

Note. $N = 371$. Standardized coefficients presented from maximum likelihood models. All models are fully saturated and include correlation between academic outcomes. FIML used to impute values for missing covariate values. District fixed effects and control for assessor with low-scoring children also included as covariates. Standard errors are clustered at the baseline school level.

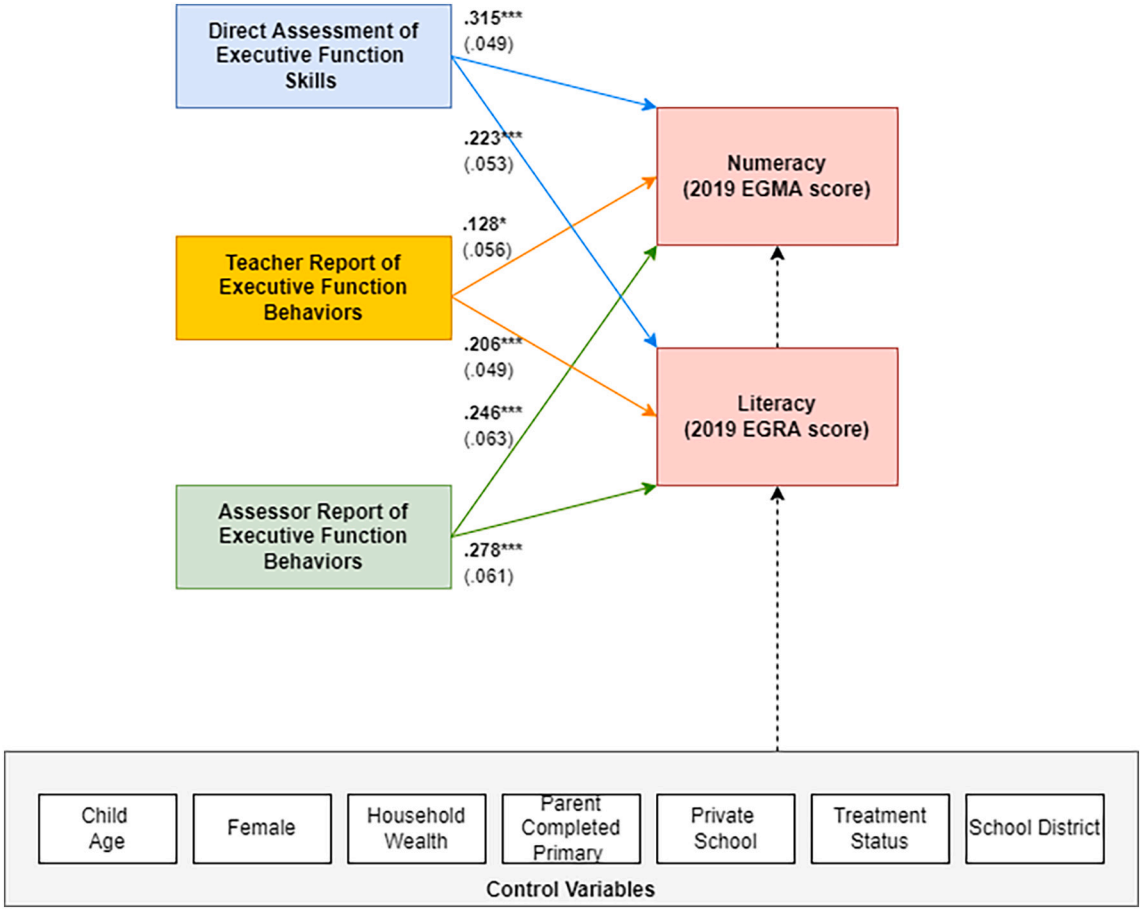


Fig. 1. Model 1 Cross-sectional association among executive function measures and academic skills.
Note. The path analysis results show associations among executive function measures and academic skills while controlling for covariates. Standard errors are in parentheses.
*$p < .05$, **$p < .01$, ***$p < .001$.

given environment. Direct assessment of EF skills and assessor-report of EF behaviors had the highest association among the three measures. Plausible explanations for this finding include that both measures shared the same context, as assessors observed children during the direct assessment and immediately recorded how the child behaved. Assessor-report of EF behaviors may capture some aspects of EF, such as "pays attention to instructions and demonstrations," that are important for performing well on the direct assessment of EF skills. It is also possible that assessors were biased toward children who answered more questions correctly and rated them with higher EF behaviors, although this is less likely for a tablet-based direct assessment where assessors were not immediately aware of children's performance. Compared to direct assessment and assessor-report, we documented a smaller association between direct assessment and teacher-report. This may be due to the different contexts of these EF measures, as teachers observe children's behavior in classroom settings and not during the direct assessment of EF and learning skills.

Furthermore, teacher- and assessor-report of EF behaviors demonstrated a small association. This finding supports previous theory that teacher-report may reflect children's holistic EF behaviors in everyday classroom settings, whereas assessor-report measures EF behaviors in a specific assessment environment (McCoy, 2019). Although the teacher-report and assessor-report include similar items related to attention, such as "pays attention" and "pays attention to instructions and demonstration," respectively, children may demonstrate different attention-related behaviors in the classroom compared to when they are participating in a formal assessment. In teacher-directed Ghanaian classrooms, "follows teacher's verbal directions" may be a prevalent classroom norm that is not captured by the assessor-report of EF behaviors. Teachers also observe children in a group setting rather than an individual one-on-one setting and may capture components of EF behaviors that involve cooperation and focusing on task completion in a more interactive environment. Moreover, teacher ratings of EF behaviors may be subject to a halo effect, in which teachers' perception of a child's general behavior can influence their rating of EF behaviors (McCoy, 2019). Future research can use assessor-report of EF behaviors on a different day or during classroom activities to understand how assessor-reports overlap with direct assessments of EF skills outside of a common assessment setting and how assessor-report is associated with teacher-report of EF behaviors in similar settings.

Unique contribution of directly assessed EF skills

Our study showed that greater EF skills were related to better performance on both concurrent literacy and numeracy tests when accounting for teacher- and assessor-reports of related behaviors in this sample of Ghanaian school children. This finding extends existing studies of early childhood in LMICs (Lan et al., 2011; von Suchodoletz et al., 2015; Willoughby et al., 2019) and prior work using multiple EF measures in HICs (Dekker et al., 2017;Gerst et al., 2017 ; Schmitt et al., 2014) by establishing the unique contribution of EF skills to concurrent academic skills in middle childhood in a West African context.

Corroborating Schmitt et al.' (2014) findings in the U.S, we found that direct assessment of EF skills had a larger concurrent association

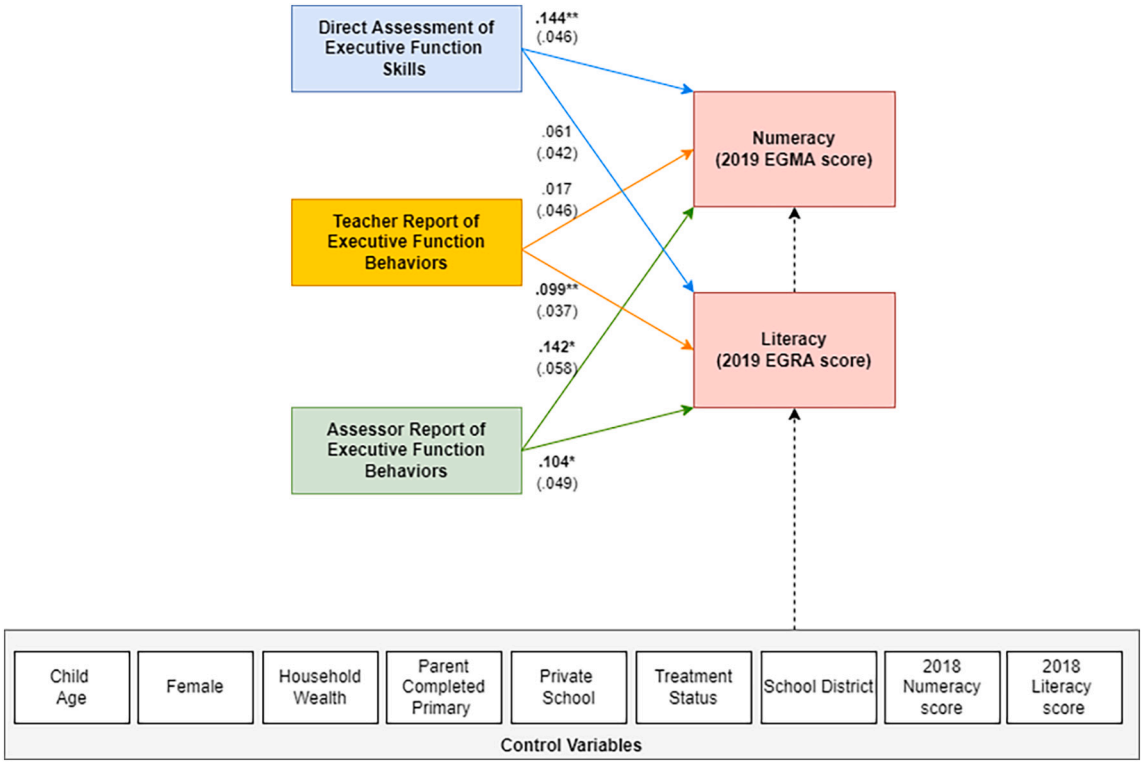


Fig. 2. Model 2 Lagged association among executive function measures and academic skills.
Note. The path analysis results show associations among executive function measures and academic skills while controlling for previous academic achievement and other covariates. Standard errors are in parentheses.
*$p < .05$, **$p < .01$, ***$p < .001$.

with numeracy than literacy. EF skills also emerged as a more robust predictor of numeracy skills than literacy skills when accounting for previous academic skills, similar to longitudinal studies in HICs (Blair et al., 2015; Lenes et al., 2020). These results align with previous meta-analyses that demonstrate that the specific EF skills of inhibitory control and working memory, both of which we measured in our study, positively contribute to numeracy skills (e.g., Allan et al., 2014; Friso-van den Bos et al., 2013). The relevance of EF skills for learning reflects the unique contextual demands of middle childhood experiences in Ghana. Although children apply EF skills in multiple ways, direct assessments measure EF skills in a standardized setting instead of during everyday activities. Ghanaian students may apply EF skills in similar standardized settings during numeracy tests. Given the unique relevance of direct assessment of EF skills for numeracy skills, future research might employ brief EF tasks to assess numeracy-related capacities of children who have not had access to formal math instruction. Furthermore, targeting EF skills may also promote numeracy skills among Ghanaian children who struggle with solving math problems.

Unique contribution of teacher-reported EF behaviors

Teacher-reports may be particularly relevant for children's schooling outcomes, as teachers observe children in the classroom daily and have a basis of comparison with children's peers. Our study offers the first examination of teacher-report of EF behaviors in addition to direct assessment of EF skills and assessor-report of EF behaviors in middle childhood to demonstrate a unique concurrent contribution to both literacy and numeracy skills in a LMIC setting. This finding extends previous work in HICs (Gerst et al., 2017; Schmitt et al., 2014). However, the finding diverges from Dekker et al. (2017), who found that teacher-reported EF behaviors explained unique variance in concurrent literacy, but not math, when also including direct assessment of EF skills.

In our lagged model, teacher-report of EF behaviors was only uniquely relevant for literacy. This aligns with several previous longitudinal studies of literacy development in HICs (Birgisdóttir et al., 2015; Lenes et al., 2020; Lonigan et al., 2017), but fails to corroborate Lenes et al. (2020)'s finding that teacher-report longitudinally predicted both literacy and math achievement. Future scholarship should examine why teacher-report of EF behaviors is significantly associated with change in literacy when including other EF measures and further investigate the relevance of teacher classroom observations for numeracy. Our study showed that in a peri-urban Ghanaian context with large class sizes and teacher-directed instruction with limited student participation, teacher-reports remain valid measures of EF behaviors as they relate to learning outcomes.

Unique contribution of assessor reported EF behaviors

The current study established the robust significance of assessor-report of EF behaviors for both concurrent literacy and numeracy skills. Although our results extend previous work in LMICs documenting contributions of assessor-report in conjunction with direct assessment of EF skills (Willoughby et al., 2019), they diverge from an early childhood study in HICs that found assessor-report of EF behaviors did not contribute to concurrent math or literacy skills when including all three EF measures (Schmitt et al., 2014). Schmitt et al. (2014) speculated that this might be due to assessor-reports occurring during free choice period when the children were not performing cognitively demanding tasks. By contrast, our study included assessor-report items specifically related to attention and concentration during the direct assessment and cooperation with assessor requests. Together, these findings suggest that the context of assessor-report may be important and that conducting assessor-report during cognitively demanding tasks may be more relevant to understanding the EF behavior processes relevant for numeracy

and literacy skills.

Our findings further demonstrated the significance of assessor-report of EF behaviors for both literacy and numeracy skills when accounting for previous academic skills. Assessors observe how children engage in cognitively demanding tasks and rate EF behaviors indicative of how children are in classroom and everyday settings in the Ghanaian context. Our results suggest that building assessor reports into existing structured assessment protocols may offer an opportunity to gather information on foundational EF behaviors in a less resource-intensive, potentially scalable way that can inform a more holistic approach to children's education. It is important to highlight the importance of training and supervision for the reliability of assessor-reports. Field supervisors can independently complete the assessor-report while the assessor is administering the direct assessment to monitor and provide a comparison to calculate reliability of the assessor-report. Future research should be conducted with larger samples that integrate assessor-report alongside existing structured assessment protocols to test the robustness of our findings.

Practitioners and program evaluators without the resources to implement direct assessments (which can be expensive to administer) or opportunities to collect teacher-report of EF behaviors (which require teachers' time) might consider using assessor-report of EF behaviors during structured assessment protocols of other skills. The Ghana Education Service administers the EGRA and EGMA assessments alongside the National Education Assessment in standardized settings every two years in primary school (Ghana Education Service, 2018b). Administrators of these assessments—or independent assessors—could be trained to report on EF behaviors while administering academic assessments.

Limitations and future directions

Our sample is a convenience sample from the Greater Accra region of Ghana, and the contextual elements unique to this study may limit the generalizability of the findings to other LMIC settings. Across previous studies, researchers have documented varying patterns in the relation among EF constructs and academic outcomes based on the age and size of the sample, cultural context, type of measure used, and academic outcome examined (Gestsdottir et al., 2014; Jacob & Parkinson, 2015; Lenes et al., 2020). Having demonstrated the importance of EF skills and EF behaviors for academic skills and the relevance of different measures in this specific setting, we hope future research will examine similar patterns in representative samples across LMICs.

This study builds on research using the original QP4G sample that found bidirectional associations between EF skills and early literacy and numeracy skills in previous waves (Wolf & McCoy, 2019). Measuring EF skills and EF behaviors in a subsequent follow-up survey could allow us to examine if the development of EF and academic skills are reciprocally related in middle childhood as well. It is plausible that children's exposure to academic content may contribute to differences in EF skills and EF behaviors and that additional time in school can change these foundational skills. It was not possible to control for classroom quality or instruction in our models, limiting our ability to examine how classroom experiences may affect both EF and academic skills. Future research can consider including classroom observations to assess classroom quality and thus be able to further isolate the contribution of EF on academic outcomes.

Future scholarship can also extend longitudinal analyses into adolescence to examine if EF skills and EF behaviors in middle childhood predict secondary school academic achievement or tertiary educational outcomes in LMICs. Researchers can compare findings from such studies to work suggesting that EF is predictive of long-term academic outcomes beyond middle childhood in HICs (e.g., Ahmed et al., 2019; Best et al., 2011).

Although we piloted and adapted our measures of EF skills and EF behaviors for the Ghanaian context, it is important to further examine bottom-up approaches to develop EF measures relevant for primary school students in this context. Specifically, it is possible that EF assessments may be capturing other local values, such as obedience and following instructions, that the academic environment in Ghana emphasizes (Agbenyega, 2018; Akyeampong, 2017). Classroom norms focusing on teacher-directed instruction may lead teachers to have different expectations for regulatory behaviors in Ghana. For example, they may value compliance with instructions to focus on learning goals at the classroom level more than regulatory behaviors during independent activities. Future research can examine how teachers perceive and value children's EF behaviors in the classroom based on local norms. Culturally informed parenting practices and children's socialization in education systems are reflected in EF constructs as children conform to models of culturally acceptable behavior (Bindman, Hindman, Bowles, & Morrison, 2013; Trommsdorff, 2009). EF can be re-conceptualized to be more culturally relevant by considering the unique strengths of children and family structures in Ghana and other LMICs (Miller-Cotto, Smith, Wang, & Ribner, 2022). For example, additional understanding of how local communities perceive EF and whether child-centered measures align with the context are central to operationalizing EF measures in different LMICs, where collective regulation may be a better-suited construct (Haslam et al., 2019). Our study builds knowledge using adaptations of existing EF measures to demonstrate their unique contributions to academic skills and shows they have predictive validity in Ghana, where children apply EF in an understudied context with different cultural learning and socializing goals compared to HICs.

Future research can also examine what types of EF interventions are appropriate in Ghana based on the role of EF skills and EF behaviors in supporting learning. Social protection programs such as cash transfers that reduce household food insecurity and poverty can mitigate risks that contribute to EF development and can also contribute to subsequent academic outcomes (Suntheimer, Wolf, Sulik, Avornyo, & Obradović, 2022). Instructional curricula in LMICs could integrate strategies that involve intentional use of EF skills and EF behaviors to accomplish everyday learning tasks and classroom activities (Diamond & Lee, 2011). Teachers can also encourage children to do mental math that engages working memory instead of rote memorization. Teacher training can also incorporate context-appropriate activities that target EF (Suntheimer et al., 2022). Working with local schools and teachers is important to develop classroom strategies that will be effective within the Ghanaian context. The EF measures used in this study can be used to screen students who need the most support in EF, enabling teachers to target their attention to help those students develop their EF skills and EF behaviors.

Conclusion

This study analyzed the unique contributions of three EF measures—direct assessment of EF skills and teacher- and assessor-report of EF behaviors—to academic skills in Ghana. All three measures positively contributed to academic skills, which adds evidence that EF skills and EF behaviors are foundational processes relevant to literacy and numeracy across many countries and cultural contexts. Our findings provide clear evidence of the added value of moving beyond a single EF measure. EF is relevant for learning in Ghana, but children use EF in multiple ways—including during cognitively demanding standardized tasks and in everyday school settings. Our study demonstrates how different EF measures capture the different EF capabilities of children across settings. Policymakers and researchers who face resource constraints can use these findings to inform decisions about what measure or set of measures best align with their objectives for measuring and promoting cognitive processes important for children's academic skills. Direct assessment of EF skills can be used to understand processes relevant to numeracy development and teacher-report of EF behaviors can shed light onto behaviors relevant for literacy development. Incorporating assessor-report of EF behaviors during existing structured assessment protocols

may offer a promising, scalable means of assessing children's EF with relevance for both numeracy and literacy skills.

Declaration of Competing Interest

The authors have no conflicts of interest to report.

Acknowledgments

This article reflects contributions from many organizations and individuals. We would like to thank the dedicated staff at Innovations from Poverty Action, and our talented data collection supervisors and enumerators. We also thank the Ghana Education Service for their support of this project. This research was supported by a Jacobs Foundation Advanced Research Fellowship (2017-1261-07) awarded to Jelena Obradović and the Institute of Education Sciences, U.S. Department of Education, through Grant R305B140009 to the Board of Trustees of the Leland Stanford Junior University. The research reported here was also supported by the Institute of Education Sciences, U.S. Department of Education, through Grant R305B200035 to the University of Pennsylvania awarded to the third author. The opinions expressed are those of the authors and do not represent views of the Institute or the U.S. Department of Education. We would like to thank the dedicated teachers, children, and families who participated in the original QP4G study. We thank the UBS Optimus Foundation and the World Bank Strategic Impact Evaluation Fund (SIEF) for support for the original QP4G study, and the University of Pennsylvania Provost Global Engagement Fund for direct support for data collection that contributed to this article. Materials and analysis code for this study are available by emailing the corresponding author. This study's design and its analyses were not preregistered.

Appendix

Table A1
T-test results comparing demographic and school readiness characteristics of non-EF study QP4G children and EF study children at baseline.

		Non-EF study	EF study	Difference	*p*-value
		M (SD)	*M (SD)*	*(SE)*	
Demographic					
	Age	5.810	5.819	−0.009	0.902
		(0.025)	(0.066)	(0.074)	
	Female	0.491	0.496	−0.006	0.832
		(0.009)	(0.025)	(0.026)	
	Private School	0.538	0.494	0.044	0.089
		(0.008)	(0.025)	(0.026)	
School readiness skills at baseline (z-scored)					
	EF	−0.020	0.054	−0.074	0.162
		(0.017)	(0.046)	(0.053)	
	Numeracy	−0.032	0.081	−0.113	0.033
		(0.017)	(0.050)	(0.053)	
	Literacy	−0.031	0.110	−0.141	0.008
		(0.017)	(0.048)	(0.053)	
	Social-emotional	−0.027	0.121	−0.149	0.005
		(0.017)	(0.047)	(0.053)	
	Motor skills	−0.027	0.036	−0.063	0.237
		(0.017)	(0.060)	(0.053)	
	Approaches to learning	−0.009	0.068	−0.077	0.142
		(0.017)	(0.046)	(0.052)	
	N	3460	407	3867	

Note. Column 1 and 2 report the mean and standard deviation in parentheses. Column 3 reports the difference in means between Column 1 and 2 and the standard error in parentheses. Column 4 reports the *p*-value of the t-test for the difference in means.
All standardized score measures are from the International Development and Early Learning Assessment (IDELA; Pisani et al., 2018). The IDELA-4 includes EF, early numeracy, early literacy, and social-emotional skills at QP4G baseline. The IDELA-5 includes all of the items in IDELA-4 plus motor-skills. Approaches to learning is an assessor report rating the child from a scale from 1 = almost never to 4 = almost always on children's attention, confidence, concentration, diligence, pleasure, motivation, and curiosity during the IDELA tasks.

Table A2
Descriptive statistics for EF composite variables.

	Variable	1	2	3	4
1.	Hearts & Flowers: Flowers Accuracy	–			
2.	Hearts & Flowers: Mixed Avg. Accuracy	0.50***	–		
3.	Memory Game: Forward Num. Correct	0.30***	0.33***	–	
4.	Memory Game: Backward Num. Correct	0.26***	0.38***	0.44***	–
	N	365	360	363	358
	Mean	0.89	0.85	6.42	3.76
	SD	(0.14)	(0.14)	(2.58)	(2.69)
	Min	0.50	0.50	0.00	0.00
	Max	1.00	1.00	13.00	11.00

Note. * $p < .05$, ** $p < .10$, *** $p < .001$.

Table A3
Teacher-report items.

Functions well even with distractions
Is a self-starter
Works or plays well without adult support
Stays on task
Works well in a group
Pays attention
Follows teacher's verbal directions

Note. Teachers rated each EF behavior on a five-point scale (0 = Not at all, 1 = A little, 2 = Moderately well, 3 = Well, 4 = Very well) with higher scores indicating more developed EF behaviors.

Table A4
Assessor-report items and rating scales.

Pays attention to instructions and demonstration
1 = Child spends most of time off-task, inattentive
2 = Child's attention frequently drifts and requires frequent prompts
3 = Child's attention occasionally drifts, particularly at the end of activities, but is responsive to prompt
4 = Child looks closely at pictures to distinguish between them. Child attends to and complies with the Child Assessor
Sustains concentration; willing to try repetitive tasks
1 = Child not able to concentrate or persist on much of the assessment
2 = Child frequently distracted, requires multiple prompts from the Child Assessor
3 = Child occasionally distracted but generally persistent, but does not require prompt from the Child Assessor
4 = Child able to concentrate and persist with the task, even toward the end of tasks and with distractions
Distracted by sights and sounds
1 = Child is frequently distracted nearby noises or materials, and has trouble focusing even with assessor help
2 = Child occasionally becomes distracted but returns to task with several prompts
3 = Child occasionally distracted but refocuses attention with only one prompt
4 = Child does not become distracted by sounds and sights in room
Refrains from indiscriminately touching test materials
1 = Assessment often interrupted by child's hand with grabbling, touching materials and tablet
2 = Child needs multiple reminders not to touch keyboard or survey materials, has hard time stopping when it's time
3 = Child generally shows self-control but starts to touch or play with tablet or survey once or twice during assessment
4 = Child shows self-restraint even with interesting tasks and does not begin tasks or surveys until told to
Can wait during and between tasks
1 = Child is impulsive throughout Test, needs lots of boundary-setting; transitions between tasks made hard because of child's activity level/impulsivity
2 = Child is often impulsive across multiple tasks or high impulsive during one activity; the child needs multiple prompts to wait while Child Assessor gathers materials for a new task
3 = A few instances of impulsive behavior; child sometimes shows anticipation for interesting task materials but rarely needs a reminder
4 = Child waits before pointing to materials, reaching for blocks, etc., and waits patiently for new tasks to begin; no ambiguous or impulsive behaviors
Cooperates; Complies with Child Assessor's requests
1 = Child does not cooperate even when tasks are easy
2 = Child shows significant resistance, noncompliance and needs multiple prompts to get through the assessment
3 = Child shows minor indications of resistance, boredom [e.g. frowns, sighs] but completes tasks
4 = Child attempts to do the task as instructed even if the task is hard

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.appdev.2022.101437.

References

Agbenyega, J. S. (2018). Examining early childhood education system in Ghana: How can Bourdieuian theorisation support a transformational approach to pedagogy? In M. Fleer, & B. van Oers (Eds.), *International handbook of early childhood education* (pp. 673–690). Netherlands: Springer. https://doi.org/10.1007/978-94-024-0927-7_32.

Ahmed, S. F., Tang, S., Waters, N. E., & Davis-Kean, P. (2019). Executive function and academic achievement: Longitudinal relations from early childhood to adolescence. *Journal of Educational Psychology, 111*, 446–458. https://doi.org/10.1037/edu0000296

Akyeampong, K. (2017). Teacher educators' practice and vision of good teaching in teacher education reform context in Ghana—Kwame Akyeampong, 2017. *Educational Researcher, 46*(4), 194–203. https://doi.org/10.3102/0013189X17711907

Allan, N. P., Hume, L. E., Allan, D. M., Farrington, A. L., & Lonigan, C. J. (2014). Relations between inhibitory control and the development of academic skills in preschool and kindergarten: A meta-analysis. *Developmental Psychology, 50*, 2368. https://doi.org/10.1037/a0037493

Amukune, S., & Jozsa, K. (2021). The childhood executive functioning inventory (CHEXI): Psychometric proporeties and association with academic achievement in Kenyan first graders. *Journal of Psychological and Educational Research, 29*(1), 154–176.

Angrist, N., Djankov, S., Goldberg, P. K., & Patrinos, H. A. (2021). Measuring human capital using global learning data. *Nature, 592*(7854), 403–408. https://doi.org/10.1038/s41586-021-03323-7

Best, J. R., Miller, P. H., & Naglieri, J. A. (2011). Relations between executive function and academic achievement from ages 5 to 17 in a large, representative national sample. *Learning and Individual Differences, 21*(4), 327–336. https://doi.org/10.1016/j.lindif.2011.01.007

Bindman, S. W., Hindman, A. H., Bowles, R. P., & Morrison, F. J. (2013). The contributions of parental management language to executive function in preschool children. *Early Childhood Research Quarterly, 28*(3), 529–539. https://doi.org/10.1016/j.ecresq.2013.03.003

Birgisdóttir, F., Gestsdóttir, S., & Thorsdóttir, F. (2015). The role of behavioral self-regulation in learning to read: A 2-year longitudinal study of Icelandic preschool children. *Early Education and Development, 26*(5–6), 807–828. https://doi.org/10.1080/10409289.2015.1003505

Blair, C., & Raver, C. C. (2015). School readiness and self-regulation: A developmental psychobiological approach. *Annual Review of Psychology, 66*(1), 711–731. https://doi.org/10.1146/annurev-psych-010814-015221

Blair, C., Ursache, A., Greenberg, M., Vernon-Feagans, L., & Family Life Project Investigators. (2015). Multiple aspects of self-regulation uniquely predict mathematics but not letter–word knowledge in the early elementary grades. *Developmental Psychology, 51*(4), 459–472. https://doi.org/10.1037/a0038813

Buckner, J. C., Mezzacappa, E., & Beardslee, W. R. (2009). Self-regulation and its relations to adaptive functioning in low income youths. *American Journal of Orthopsychiatry, 79*(1), 19–30. https://doi.org/10.1037/a0014796

Camerota, M., Willoughby, M. T., & Blair, C. B. (2019). Speed and accuracy on the hearts and flowers task interact to predict child outcomes. *Psychological Assessment, 31*(8), 995–1005. https://doi.org/10.1037/pas0000725

Central Intelligence Agency. (2021). Ghana—The world Factbook. https://www.cia.gov/the-world-factbook/countries/ghana/#geography.

Cook, C. J., Howard, S. J., Scerif, G., Twine, R., Kahn, K., Norris, S. A., & Draper, C. E. (2019). Associations of physical activity and gross motor skills with executive function in preschool children from low-income South African settings. *Developmental Science, 22*(5). https://doi.org/10.1111/desc.12820. e12820.

Conduct Problems Prevention Research Group. (1990). Social Competence Scale (teacher version). *Fast Track Project.* Retrieved from http://www.fasttrackproject.org.

Cortés Pascual, A., Moyano Muñoz, N., & Quílez Robres, A. (2019). The relationship between executive functions and academic performance in primary education: Review and meta-analysis. *Frontiers in Psychology, 10*. https://doi.org/10.3389/fpsyg.2019.01582

Daneri, M. P., Sulik, M. J., Raver, C. C., & Morris, P. A. (2018). Observers' reports of self-regulation: Measurement invariance across sex, low-income status, and race/ethnicity. *Journal of Applied Developmental Psychology, 55*, 14–23. https://doi.org/10.1016/j.appdev.2017.02.001

Davidson, M. C., Amso, D., Anderson, L. C., & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia, 44*(11), 2037–2078. https://doi.org/10.1016/j.neuropsychologia.2006.02.006

Dekker, M. C., Ziermans, T. B., Spruijt, A. M., & Swaab, H. (2017). Cognitive, parent and teacher rating measures of executive functioning: Shared and unique influences on school achievement. *Frontiers in Psychology, 8*. https://doi.org/10.3389/fpsyg.2017.00048

Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4 to 12 years old. *Science, 333*(6045), 959–964. https://doi.org/10.1126/science.1204529

Enders, C. K. (2010). *Applied missing data analysis.* Guilford.

Finch, J. E., Garcia, E. B., Sulik, M. J., & Obradović, J. (2019). Peers matter: Links between classmates' and individual students' executive functions in elementary school. *AERA Open, 5*(1). https://doi.org/10.1177/2332858419829438, 2332858419829438.

Finders, J. K., McClelland, M. M., Geldhof, G. J., Rothwell, D. W., & Hatfield, B. E. (2021). Explaining achievement gaps in kindergarten and third grade: The role of self-regulation and executive function skills. *Early Childhood Research Quarterly, 54*, 72–85. https://doi.org/10.1016/j.ecresq.2020.07.008

Friso-van den Bos, I., van der Ven, S. H. G., Kroesbergen, E. H., & van Luit, J. E. H. (2013). Working memory and mathematics in primary school children: A meta-analysis. *Educational Research Review, 10*, 29–44. https://doi.org/10.1016/j.edurev.2013.05.003

Fuchs, L. S., Fuchs, D., Compton, D. L., Powell, S. R., Seethaler, P. M., Capizzi, A. M., … Fletcher, J. M. (2006). The cognitive correlates of third-grade skill in arithmetic, algorithmic computation, and arithmetic word problems. *Journal of Educational Psychology, 98*(1), 29–43. https://doi.org/10.1037/0022-0663.98.1.29

Fuhs, M. W., Farran, D. C., & Nesbitt, K. T. (2015). Prekindergarten children's executive functioning skills and achievement gains: The utility of direct assessments and teacher ratings. *Journal of Educational Psychology, 107*(1), 207–221. https://doi.org/10.1037/a0037366

Fuhs, M. W., Nesbitt, K. T., Farran, D. C., & Dong, N. (2014). Longitudinal associations between executive functioning and academic skills across content areas. *Developmental Psychology, 50*(6), 1698–1709. https://doi.org/10.1037/a0036633

Gerst, E. H., Cirino, P. T., Fletcher, J. M., & Yoshida, H. (2017). Cognitive and behavioral rating measures of executive function as predictors of academic outcomes in children. *Child Neuropsychology, 23*(4), 381–407. https://doi.org/10.1080/09297049.2015.1120860

Gestsdottir, S., von Suchodoletz, A., Wanless, S. B., Hubert, B., Guimard, P., Birgisdottir, F., … McClelland, M. (2014). Early behavioral self-regulation, academic achievement, and gender: Longitudinal findings from France, Germany, and Iceland. *Applied Developmental Science, 18*(2), 90–109. https://doi.org/10.1080/10888691.2014.894870

Ghana Education Service. (2018a). *Education sector performance report.* Ministry of Education.

Ghana Education Service. (2018b). Ghana 2016 national education assessment: Report of findings. https://sapghana.com/data/documents/2016-NEA-Findings-Report_17Nov2016_Public-FINAL.pdf.

Ghana Education Service, RTI International, & Education Assessment and Research Centre. (2016). *Ghana 2015 early grade Reading assessment and early grade mathematics assessment: Report of findings*. https://ierc-publicfiles.s3.amazonaws.com/public/resources/Ghana%202015%20EGRA-EGMA_22Nov2016_FINAL.pdf.

Haslam, D., Mejia, A., Thomson, D., & Betancourt, T. (2019). Self-regulation in low- and middle-income countries: Challenges and future directions. *Clinical Child and Family Psychology Review, 22*(1), 104–117. https://doi.org/10.1007/s10567-019-00278-0

Heine, S. J., Lehman, D. R., Peng, K., & Greenholtz, J. (2002). What's wrong with cross-cultural comparisons of subjective Likert scales?: The reference-group effect. *Journal of Personality and Social Psychology, 82*(6), 903. https://doi.org/10.1037/0022-3514.82.6.903

Jacob, R., & Parkinson, J. (2015). The potential for school-based interventions that target executive function to improve academic achievement: A review. *Review of Educational Research, 85*(4), 512–552. https://doi.org/10.3102/0034654314561338

Jukes, M. C. H., Mgonda, N. L., Tibenda, J. J., Gabrieli, P., Jeremiah, G., Betts, K. L., … Bub, K. L. (2021). Building an assessment of community-defined social-emotional competencies from the ground up in Tanzania. *Child Development.* https://doi.org/10.1111/cdev.13673. n/a(n/a).

Kamran, M., Liang, Y., & Trines, S. (2019). *Education in Ghana*. WENR. April 16 https://wenr.wes.org/2019/04/education-in-ghana.

Lan, X., Legare, C. H., Ponitz, C. C., Li, S., & Morrison, F. J. (2011). Investigating the links between the subcomponents of executive function and academic achievement: A cross-cultural analysis of Chinese and American preschoolers. *Journal of Experimental Child Psychology, 108*(3), 677–692. https://doi.org/10.1016/j.jecp.2010.11.001

Lenes, R., McClelland, M. M., ten Braak, D., Idsøe, T., & Størksen, I. (2020). Direct and indirect pathways from children's early self-regulation to academic achievement in fifth grade in Norway. *Early Childhood Research Quarterly, 53*, 612–624. https://doi.org/10.1016/j.ecresq.2020.07.005

Lonigan, C. J., Allan, D. M., & Phillips, B. M. (2017). Examining the predictive relations between two aspects of self-regulation and growth in preschool children's early literacy skills. *Developmental Psychology, 53*(1), 63–76. https://doi.org/10.1037/dev0000247

McClelland, M. M., Acock, A. C., & Morrison, F. J. (2006). The impact of kindergarten learning-related skills on academic trajectories at the end of elementary school. *Early Childhood Research Quarterly, 21*(4), 471–490. https://doi.org/10.1016/j.ecresq.2006.09.003

McCoy, D. C. (2019). Measuring young children's executive function and self-regulation in classrooms and other real-world settings. *Clinical Child and Family Psychology Review, 22*(1), 63–74. https://doi.org/10.1007/s10567-019-00285-1

McKown, C. (2019). Challenges and opportunities in the applied assessment of student social and emotional learning. *Educational Psychologist, 54*(3), 205–221. https://doi.org/10.1080/00461520.2019.1614446

Miller-Cotto, D., Smith, L. V., Wang, A. H., & Ribner, A. D. (2022). Changing the conversation: A culturally responsive perspective on executive functions, minoritized children and their families. *Infant and Child Development, 31*(1). https://doi.org/10.1002/icd.2286. e2286.

Miyake, A., & Friedman, N. P. (2012). The nature and organization of individual differences in executive functions: Four general conclusions. *Current Directions in Psychological Science, 21*(1), 8–14. https://doi.org/10.1177/0963721411429458

Morgan, P. L., Farkas, G., Wang, Y., Hillemeier, M. M., Oh, Y., & Maczuga, S. (2019). Executive function deficits in kindergarten predict repeated academic difficulties across elementary school. *Early Childhood Research Quarterly, 46*, 20–32. https://doi.org/10.1016/j.ecresq.2018.06.009

Obradović, J. (2019). The assessment of motivation, effort, and self-regulation (AMES). https://sparklab.stanford.edu/ames.

Obradović, J., Finch, J. E., Connolly, C., Siyal, S., & Yousafzai, A. K. (2022). *The unique relevance of executive functions and self-regulation behaviors for understanding early childhood experiences and preschoolers' outcomes in rural Pakistan.* Developmental Science. In press.

Obradović, J., Sulik, M. J., Finch, J. E., & Tirado-Strayer, N. (2018). Assessing students' executive functions in the classroom: Validating a scalable group-based procedure. *Journal of Applied Developmental Psychology, 55*, 4–13. https://doi.org/10.1016/j.appdev.2017.03.003

Obradović, J., & Willoughby, M. T. (2019). Studying executive function skills in young children in low- and middle-income countries: Progress and directions. *Child Development Perspectives, 13*(4), 227–234. https://doi.org/10.1111/cdep.12349

Obradović, J., Yousafzai, A. K., Finch, J. E., & Rasheed, M. A. (2016). Maternal scaffolding and home stimulation: Key mediators of early intervention effects on children's cognitive development. *Developmental Psychology, 52*(9), 1409–1421. https://doi.org/10.1037/dev0000182

Opoku-Amankwa, K. (2009). 'Teacher only calls her pets': Teacher's selective attention and the invisible life of a diverse classroom in Ghana. *Language and Education, 23*(3), 249–262. https://doi.org/10.1080/09500780802582539

Phillips, B. M., & Lonigan, C. J. (2010). Child and informant influences on behavioral ratings of preschool children. *Psychology in the Schools, 47*(4), 374–390. https://doi.org/10.1002/pits.20476

Pisani, L., Borisova, I., & Dowd, A. J. (2018). Developing and validating the international development and early learning assessment (IDELA). *International Journal of Educational Research, 91*, 1–15. https://doi.org/10.1016/j.ijer.2018.06.007

RTI International. (2014). Early grade mathematics assessment (EGMA) toolkit. https://shared.rti.org/content/early-grade-mathematics-assessment-egma-toolkit.

RTI International. (2015). *Early grade reading assessment (EGRA) toolkit.* United States Agency for International Development: Second Edition.

Schmitt, S. A., Geldhof, G. J., Purpura, D. J., Duncan, R., & McClelland, M. M. (2017). Examining the relations between executive function, math, and literacy during the transition to kindergarten: A multi-analytic approach. *Journal of Educational Psychology, 109*(8), 1120–1140. https://doi.org/10.1037/edu0000193

Schmitt, S. A., Pratt, M. E., & McClelland, M. M. (2014). Examining the validity of behavioral self-regulation tools in predicting preschoolers' academic achievement. *Early Education and Development, 25*(5), 641–660. https://doi.org/10.1080/10409289.2014.850397

Schreiner, M., & Woller, G. (2010). *A simple poverty scorecard for Ghana* (p. 212). Consultative Group to Assist the Poorest. http://microfinance.com/English/Papers/Scoring_Poverty_Ghana_EN_2005.ppdf.

Smith-Donald, R., Raver, C. C., Hayes, T., & Richardson, B. (2007). Preliminary construct and concurrent validity of the preschool self-regulation assessment (PSRA) for field-based research. *Early Childhood Research Quarterly, 22*(2), 173–187. https://doi.org/10.1016/j.ecresq.2007.01.002

Spiegel, J. A., Goodrich, J. M., Morris, B. M., Osborne, C. M., & Lonigan, C. J. (2021). Relations between executive functions and academic outcomes in elementary school children: A meta-analysis. *Psychological Bulletin, 147*(4), 329–351. https://doi.org/10.1037/bul0000322

von Suchodoletz, A., Uka, F., & Larsen, R. A. A. A. (2015). Self-regulation across different contexts: Findings in young Albanian children. *Early Education and Development, 26*(5–6), 829–846. https://doi.org/10.1080/10409289.2015.1012189

Sulik, M. J., & Obradović, J. (2018). Teachers' rankings of children's executive functions: Validating a methodology for school-based data collection. *Journal of Experimental Child Psychology, 173*, 136–154. https://doi.org/10.1016/j.jecp.2018.01.016

Suntheimer, N. M., Wolf, S., Sulik, M. J., Avornyo, E. A., & Obradović, J. (2022). Executive function mediates the association between cumulative risk and learning in Ghanaian schoolchildren. *Developmental Psychology*. https://doi.org/10.1037/dev0001372. No Pagination Specified-No Pagination Specified.

The World Bank. (2020a). Pupil-teacher ratio, primary—Ghana | data. https://data.worldbank.org/indicator/SE.PRM.ENRL.TC.ZS?locations=GH.

The World Bank. (2020b). School enrollment, primary (% net)—Ghana | data. https://data.worldbank.org/indicator/SE.PRM.NENR?locations=GH.

Toplak, M. E., West, R. F., & Stanovich, K. E. (2013). Practitioner review: Do performance-based measures and ratings of executive function assess the same construct?: Performance-based and rating measures of EF. *Journal of Child Psychology and Psychiatry, 54*(2), 131–143. https://doi.org/10.1111/jcpp.12001

Trommsdorff, G. (2009). Culture and development of self-regulation. *Social and Personality Psychology Compass, 3*(5), 687–701. https://doi.org/10.1111/j.1751-9004.2009.00209.x

Willoughby, M. T., Piper, B., Oyanga, A., & King, K. M. (2019). Measuring executive function skills in young children in Kenya: Associations with school readiness. *Developmental Science, 22*(5). https://doi.org/10.1111/desc.12818. e12818.

Wolf, S. (2019). Year 3 follow-up of the 'quality preschool for Ghana' interventions on child development. *Developmental Psychology, 55*(12), 2587–2602. https://doi.org/10.1037/dev0000843

Wolf, S., Aber, J. L., Behrman, J. R., & Tsinigo, E. (2019). Experimental impacts of the "quality preschool for Ghana" interventions on teacher professional well-being, classroom quality, and children's school readiness. *Journal of Research on Educational Effectiveness, 12*(1), 10–37. https://doi.org/10.1080/19345747.2018.1517199

Wolf, S., & McCoy, D. C. (2019). The role of executive function and social-emotional skills in the development of literacy and numeracy during preschool: A cross-lagged longitudinal study. *Developmental Science, 22*(4). https://doi.org/10.1111/desc.12800. e12800.

Zelazo, P. D., Blair, C. B., & Willoughby, M. T. (2016). *Executive function: Implications for education*. NCER 2017-2000. National Center for Education Research. National Center for Education Research https://eric.ed.gov/?id=ED570880.