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Early executive functioning in a global context: Developmental continuity and family protective factors

Jelena Obradović[1] | Jenna E. Finch[2] | Ximena A. Portilla[3] | Muneera A. Rasheed[4] | Nicole Tirado-Strayer[5] | Aisha K. Yousafzai[6]

[1]Graduate School of Education, Stanford University, Stanford, California

[2]Department of Psychology, University of Nebraska-Lincoln, Lincoln, Nebraska

[3]Family Well-Being and Child Development area, MDRC, New York, New York

[4]Department of Paediatrics and Child Health, Aga Khan University, Karachi, Pakistan

[5]Center for Prevention and Early Intervention, WestEd, San Fransisco, California

[6]Department of Global Health and Population, Harvard T.H. Chan School of Public Health, Harvard University, Boston, Massachusetts

Correspondence
Jelena Obradović, Stanford University, Stanford, CA.
Email: jelena.obradovic@stanford.edu

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Abstract

This study extends the methodological and theoretical understanding of executive functions (EFs) in preschoolers from low- and middle-income countries (LMIC). First, the authors describe a rigorous process of adapting and evaluating six EF tasks to produce a culturally and developmentally appropriate measure of emerging EFs in a large sample of at-risk children in rural Pakistan. Next, the authors identify critical developmental and family factors that relate to preschoolers' EFs over the first 4 years of life. Direct assessment of children's general cognitive skills at age two showed developmental continuity with EFs at age four, and these early cognitive skills mediated the effect of an antecedent parenting intervention on EFs as well as associations of targeted individual and family factors with EFs. Furthermore, directly assessed maternal cognitive capacities and observed maternal scaffolding uniquely predicted EFs in preschoolers. This study is also the first to demonstrate a significant overlap between direct assessments of IQ and EFs in young children from LMIC. Children's general intelligence mediated the associations of EFs with antecedent physical growth and cognitive skills as well as concurrent family factors (maternal verbal intelligence, maternal scaffolding, and home stimulation). After controlling for shared variance between preschoolers' general intelligence and EFs, three factors emerged as unique predictors of EFs: exposure to an early parenting intervention, physical growth status at age two, and number of older siblings. The findings have important implications for the design of interventions that aim to improve EFs in young children in LMIC. A video abstract of this article can be viewed at https://vimeo.com/316329544/5abde94cd7

KEYWORDS
adversity, cognitive development, executive functions, low- and middle-income countries, parenting intervention

1 | INTRODUCTION

Interest in the developmental trajectories, correlates, and applications of early executive functions has grown immensely in the last decade. Extensive research has linked executive function (EF) skills to a wide range of social–emotional and school outcomes (e.g., Liew, 2012). Crucially, researchers have found that EF skills can be hindered by environmental adversity but improved through positive parenting behaviors and diverse intervention efforts (e.g., Diamond, 2013; Finch & Obradović, 2017). However, most of this work is based on studies of children in high-income countries (HIC; defined by the World Bank as having annual Gross National Income per capita >US$12,235). We know very little about early EF development in low-and middle-income countries (LMIC) where children

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face high levels of adversity, including infections, malnutrition, and inadequate stimulation (Walker et al., 2011). Although EFs can be construed as universal skills that support any goal-directed behavior, EF assessment and exposure to family factors may be culturally and contextually dependent. This study extends methodological and conceptual understanding of emerging EFs in highly disadvantaged children; in this case, a large birth-cohort of at-risk children in rural Pakistan. Using a developmentally and culturally appropriate battery of adapted EF tasks, we demonstrated how antecedent and concurrent measures of cognitive skills relate to emergent EFs in preschoolers in a low-income, rural setting. Furthermore, we identified unique protective factors that directly and indirectly predict EFs, after controlling for the overlap of EFs with general cognitive skills. Knowing which proximal and distal experiences relate to emerging EFs in the context of extreme chronic adversity can inform intervention efforts aimed at promoting healthy early child development in disadvantaged rural LMIC contexts.

RESEARCH HIGHLIGHTS

- We measured emerging executive functions (EFs) in a large sample of disadvantaged 4-year-olds in rural Pakistan, using six culturally and developmentally appropriate tasks.
- Cognitive skills at age two were longitudinally associated with EFs and mediated how an early intervention, home stimulation, and maternal scaffolding were related with EFs.
- Preschoolers' EFs were independently predicted by observed maternal cognitive scaffolding practices and directly assessed maternal cognitive capacities.
- The early parenting intervention, physical growth status at age two, and number of older siblings uniquely predicted EFs in preschoolers, after controlling for child IQ.

1.1 | Executive functions as a culturally universal index of early development

EFs are higher-order cognitive skills that enable individuals to regulate their attention, behavior, and emotions. Strong EFs are associated with lower levels of behavioral and emotional problems and greater social competence, school engagement, and emergent academic skills (Diamond, 2013; Obradović, Portilla, & Boyce, 2012). Studies of at-risk children in the United States reveal that these skills may be especially important for promoting resilience in contexts of adversity (Obradović, 2010). Performance on EF tasks has been linked to activation of specific brain regions (Bunge & Crone, 2009) and provides a proxy measure of neurocognitive development when direct assessments of neurobiological processes are not feasible. Given the broad implication of EFs for salient domains of adaptive functioning, assessment of EF skills can be used as an index of overall early childhood development. However, most studies have been conducted in HIC, which greatly limits the generalizability of findings.

We propose that basic EF skills, which enable children to control their impulses, ignore distracting stimuli, hold relevant information in the mind, and shift between competing rules or attentional demands, can be construed as a culturally universal set of skills that promote culturally dependent, goal-directed behaviors. Similar factors may hinder (e.g., poverty) or promote (e.g., positive parenting) EF development across different cultures (Hackman, Gallop, Evans, & Farah, 2015; Hamadani et al., 2014), although children's exposure to these factors may differ. Likewise, neural structures that support EFs appear to be culturally invariant (Tarullo et al., 2017), but the activation of these brain regions may vary as a function of the contextual influences that shape the developmental trajectories of EFs (Sheridan, Sarsour, Jutte, D'Esposito, & Boyce, 2012). Indeed, mean level differences in EFs across cultural, racial, and ethnic groups do not seem to reflect fundamental discrepancies in the underlying structure of EFs, but rather variability in contextual influences (Lan, Legare, Ponitz, Li, & Morrison, 2011; Li-Grining, 2012; Sulik et al., 2010).

Since LMIC children's limited access to educational programming, media, and modern technology can affect their comprehension of cognitive tests' instructions, stimuli, and concepts, it is critical that EF tasks' surface-level characteristics are designed to minimize such biases. Previous efforts to adapt EF assessments for use with preschool children in LMIC exposed considerable challenges. For example, evaluation of five adapted EF tasks used with preschoolers in Indonesia revealed that children's reluctance to participate in two tasks led to low scores and missing data, whereas a third task showed poor test–retest reliability and no expected correlation with age (Prado et al., 2010). Fernald, Weber, Galasso, and Ratsifandrihamanana (2011) reported significant floor and ceiling effects on a locally adapted inhibitory control task used with 3- to 6-year-olds in Madagascar, highlighting the need to identify EF tasks that provide adequate variability in LMIC settings. Furthermore, studies that resort to a single EF task (Fernald et al., 2011; McCoy, Zuilkowski, & Fink, 2015; Patel et al., 2013) may not yield a reliable and valid measure of EF skills due to task-specific sources of measurement error (Willoughby, Pek, Blair, & Family Life Project Investigators, 2013). We identified a clear need to develop a battery of play-based EF tasks for young children in LMIC, who tend to be inhibited in novel testing situations and hesitant to interact with strangers, because of their unfamiliarity with standardized testing procedures and materials as well as a general lack of experiences outside of their homes. It is crucial that researchers do not confound children's reluctance to engage or their limited understanding of assessment procedures with an actual lack of EF skills.

The development of EF skills during the preschool period, a time of heightened sensitivity to environmental influences and preparation for the school transition, has been understudied in LMIC. We also lack studies that examine how commonly employed measures of cognitive development relate to direct assessment of EFs. There is a need to examine longitudinal continuity between early cognitive skills and preschoolers' performance of EF tasks. Furthermore, by investigating the overlap of emergent EF skills with concurrent measures of general intelligence, we can identify factors that uniquely relate to emergent EFs.

1.2 | Early life experience and executive functions

Despite the important role that EFs play in promoting resilient adaptation of at-risk children (Lengua, Bush, Long, Kovacs, & Trancik, 2008; Obradović, 2010), young children from disadvantaged socioeconomic backgrounds in the United States perform worse on EF tasks when compared to their more advantaged peers (Lawson, Hook, Hackman, & Farah, 2014). For example, financial difficulties and chronic poverty have been linked to EF deficits in 4-year-olds, over and above other family characteristics (Raver, Blair, & Willoughby, 2013). Similarly, family wealth and maternal education have been linked to EFs and related cognitive skills in preschoolers from Ecuador (Schady, 2011), Madagascar (Fernald et al., 2011), Indonesia (Prado et al., 2010) and Ghana (Wolf & McCoy, 2017). Less is known about how proximal early life experiences uniquely relate to the development of emergent EFs in rural LMIC settings, where young children and their parents lack basic resources, have limited access to health services and education opportunities, and face extreme levels of chronic adversity. As a result, these children experience higher levels of malnutrition, growth retardation, infectious illnesses, maternal illiteracy and depression, inadequate housing conditions, and cognitive stimulation than at-risk children growing up HIC (Black et al., 2017; Grantham-McGregor et al., 2007).

Experiences of poverty in LMIC have been linked to high incidence of nutritional deficiencies and infection, which can lead to early growth retardation and stunting in young children (Grantham-McGregor et al., 2007). Stunting during the first 2 years of a child's life represents a serious, longitudinal risk for cognitive development (Black et al., 2017; Grantham-McGregor et al., 2007). Although recovery from early stunting is possible, benefits of recovery for cognitive development are inconsistent. For example, micronutrient supplementation during the prenatal period, but not during the preschool years, yielded higher EFs in 7- to 9-year-olds in Nepal (Christian et al., 2010; Murray-Kolb et al., 2012). On the other hand, change in linear growth from infancy to age eight and recovery from early stunting were associated with improved cognitive achievement in children in Ethiopia, India, Peru, and Vietnam (Crookston et al., 2013). Given the profound effects of early growth retardation on brain development, it is important to test whether food security and children's early height-for-age, a proxy for healthy physical growth, are related to emerging EFs in LMIC, independent from their association with global measures of antecedent and concurrent general intelligence.

The quality of home stimulation and caregiving has been hypothesized as a second key pathway by which poverty undermines child development outcomes in LMIC (Grantham-McGregor et al., 2007). These proximal family processes have been shown to promote early EFs (Fay-Stammbach, Hawes, & Meredith, 2014) and mediate the link between socioeconomic risk and EFs in HIC studies (Hackman et al., 2015; Sarsour et al., 2011). A few recent studies have extended this work to LMIC settings. In the present sample of preschoolers living in rural Pakistan, Obradović, Yousafzai, Finch, and Rasheed (2016) found that the quality of concurrent home stimulation as well as earlier and concurrent observed measures of maternal scaffolding independently predicted EFs. Using a cross-sectional study of Zambian 6-year-olds, McCoy et al. (2015) showed that concurrent reading activities at home mediated the link between family wealth and children's EFs. In a relatively more advantaged sample of urban Argentinian preschoolers, exposure to literacy activities and computer resources in the home mediated the effect of more distal family socioeconomic factors (Lipina et al., 2013; Segretin et al., 2014). In contrast, Wolf and McCoy (2017) did not find a significant association between caregivers' stimulation practices and EFs of Ghanaian 5-year-olds. Moreover, Patel et al. (2013) found that after accounting for the schooling exposure of 7- to 9-year-olds in Nepal, the quality of home stimulation was not related to children's performance on an EF task, highlighting the need to test the unique contribution of family processes before school entry.

Given the striking parallels in how family processes relate to both measures of EFs and general intelligence in young children in LMIC (Hamadani et al., 2014; McCoy et al., 2015; Obradović, Yousafzai, et al., 2016), there is a need to model rigorous HIC studies in identifying unique family predictors of early EFs, after controlling for the shared variance with related measures of general intelligence (Bernier, Carlson, Deschênes, & Matte-Gagné, 2012; Obradović, Portilla, & Ballard, 2016; Sarsour et al., 2011). Furthermore, knowing whether the associations of family enrichment processes with EFs are mediated by antecedent or concurrent measures of broad cognitive skills can inform the design and timing of early intervention programs specifically targeting early EFs in LMIC.

Recently, maternal cognitive and self-regulatory capacities have been linked to EFs in children in HIC, both directly and indirectly through parenting behaviors (Cuevas et al., 2014; Deater-Deckard & Sturge-Apple, 2017; Distefano, Galinsky, McClelland, Zelazo, & Carlson, 2018). Understanding the role of directly assessed maternal cognitive capacities is especially relevant in rural LMIC contexts where a majority of women have no formal education. In the present sample of highly disadvantaged mothers in rural Pakistan, maternal working memory, short-term memory, and verbal intelligence have been shown to uniquely predict maternal scaffolding behaviors (Obradović et al., 2017). However, it remains unknown whether these maternal cognitive capacities are directly or indirectly related to preschoolers' EFs. Knowing whether maternal cognitive capacities and specific parenting skills are independently linked to children's emerging EFs can inform the design of two-generation interventions that target self-regulation skills in both caregivers and their children.

1.3 | Current study

This study was designed to address methodological and empirical gaps in the research on early EF development in preschool children from disadvantaged, rural areas of LMIC. First, we engaged in a rigorous process of: (a) selecting, adapting, and administering individual EF tasks; (b) examining children's understanding of and performance on these tasks; and (c) evaluating the psychometric properties of the EF composite. Second, we identified salient child and family factors that uniquely contributed to preschoolers' EFs across time.

We studied a large birth cohort of children in Pakistan, a primarily agricultural, lower-middle-income country (defined by annual Gross National Income per capita between $1,006 and $3,955 USD) with 21% of the population living below the international poverty line of $1.25 USD daily (UNDP, 2014). The experience of Pakistani children reflects many challenges faced by children in LMIC, including high rates of infant and under-five mortality (NIPS & ICF International, 2013), health and educational disparities across urban and rural areas (Di Cesare et al., 2015; UNICEF, 2013), poor access to education, low school attendance amplified by gender inequalities, and high prevalence of adult illiteracy (UNICEF, 2013). The low quality of early education, due to inadequate teacher training, infrastructure, and school resources, heightens the role of the family in fostering early cognitive development.

Children in this study were recruited at birth to participate in the Pakistan Early Child Development Scale-Up (PEDS) Trial, a community-based, cluster-randomized control trial a 2 × 2 factorial design that evaluated the impact of integrating early responsive stimulation (RS) and enhanced nutrition (EN) interventions within government health services to promote child development (Yousafzai, Rasheed, Rizvi, Armstrong, & Bhutta, 2014). The RS intervention promoted sensitive and responsive caregiving via individualized coaching, support, and feedback during monthly home visits and community group meetings; whereas the EN intervention expanded on existing health, hygiene, and basic nutrition education, and included delivery of micronutrient supplements (see Yousafzai et al., 2014 for details).

This study extended published research on the direct and indirect effects of the RS intervention on children's EFs at age four (Obradović, Yousafzai, et al., 2016; Yousafzai et al., 2016) in three key ways. First, we examined *developmental continuity* by testing how general cognitive skills at age two predicted emerging EFs in preschoolers, after controlling for socioeconomic factors at birth, direct effects of the PEDS interventions, as well as targeted family factors and children's physical growth at age two. This model enabled us to test the hypothesis that children's cognitive skills at the completion of the intervention trial would partially mediate the effects of the RS intervention and the targeted family factors at age two on preschoolers' EFs. Second, we examined whether maternal cognitive skills (working memory, short-term memory, and verbal intelligence) directly contributed to children EFs in LMIC. We hypothesized that these maternal cognitive skills, partially reflecting differences in maternal capacities to plan and adapt caregiving behaviors, would uniquely predict children's EFs, over and above the published contribution of the concurrent home stimulation and maternal scaffolding (Obradović, Yousafzai, et al., 2016). This model enabled us to test whether home stimulation and maternal scaffolding would remain significant family predictors of children EFs after the inclusion of maternal cognitive capacities, which partially reflect family socioeconomic resources and shared mother–child genetic endowment. Third, we identified shared variance between emergent EFs and concurrent measures of general intelligence. By accounting for the overlap between EFs and intelligence, this study is the first to identify salient developmental factors from birth to age four, including the exposure to the RS intervention, that are uniquely relevant for development of early EFs in the context of extreme, chronic adversity.

2 | METHOD

2.1 | Participants

Participants included 1,302 children (46% girls) and primary caregivers (99% mothers) who were enrolled in the original PEDS Trial from birth to age 2 years and were included in a longitudinal follow-up at age four. Attrition at the follow-up (N = 187, 12.56%) was predominantly due to disabilities, deaths, and migration (see below for a more detailed description of missing data). The attrited group had a significantly higher share of children who received the EN intervention compared to the group of children who were retained in the study ($t(1487) = 3.029$, $p = 0.003$), but otherwise the two groups did not differ in terms of RS exposure or any study variables from the baseline, 18-month, and 24-month assessments. The final analytic sample was limited to 1,144 children who had a valid EF outcome score.

Participants resided in the predominantly agricultural Naushero Feroze District, in Sindh Province, Pakistan, and were exposed to high levels of poverty. Monthly household income averaged $100 USD ($SD$ = $140). Primary school attendance in the region is low, and in this sample 68% of mothers and 31% of fathers were illiterate. At baseline, mothers were 28.20 years old (SD = 5.85, range = 15.12–59.46) and reported an average 2.19 years of education (SD = 3.69; range = 0–16). At the end of the intervention, when children were 24 months old, approximately one third of families reported food insecurity (33%), and a substantial proportion of children were underweight (43%), or exhibited stunting (61%) or wasting (27%).

2.2 | Procedures

A birth-cohort of children, born between April 1, 2009, and March 31, 2010, was invited to enroll in the PEDS trial with their primary caregivers. This study employs data collected during the PEDS Trial (when children were 0–2.5, 18, and 24 months old), and at the 48-month follow-up. Most children were assessed within a month of their birthday at each time point. The assessment team received extensive training on interacting with children and families, understanding the evaluation constructs, administering measures, and dealing with assessment barriers. Throughout the PEDS trial, data were collected during home visits. At age four, data were collected during a 3-hr center visit and a 3-hr home visit by the team that was masked to the original intervention assignment. Child and maternal assessments were alternated in a predetermined sequence to give both participants time to rest, and cognitive tests were administered at the beginning of the center visit to ensure that children's performance did not suffer from fatigue. In addition to the set rest periods, the assessors were trained to identify when participants needed to take a break for refreshments, nap, playing, or bathroom. All questionnaires and child assessments were administered in the local language, Sindhi. A multidisciplinary team of experts and local staff spent 6 months adapting all selected measures for administration in a new cultural context with a highly disadvantaged population.

2.3 | Measures

2.3.1 | Executive function composite

Since there was no existing EF battery for preschoolers in rural LMIC, we completed an extensive process of task selection, adaptation, and evaluation (see Appendix A). The final EF assessment consisted of six tasks that assessed children's inhibitory control (IC), working memory (WM) and cognitive flexibility (CF). For all tasks, we increased the number of practice trials to improve task comprehension, since many aspects of the testing procedure were novel to this population and children tended to be reticent in this context. More information on the administration procedures for the EF tasks can be found in Appendix B.

The *Fruit Stroop* (IC task) assessed the child's ability to focus on a subdominant perceptual feature of an image, rather than on a dominant feature (Carlson, 2005). Children were shown three pictures, each depicting a small fruit embedded within a different larger fruit (e.g., a small apple inside a large banana) and were asked to point to the small fruit, which required suppressing the inclination to choose the large, more salient fruit. The total score reflected the percent correct across three test trials ($\alpha = 0.65$). The *Knock-Tap Game* (IC task) assessed children's ability to implement a set of rules and suppress an imitation of the assessor's actions (Molfese et al., 2010). Using their hand, children were asked to tap on the table after the assessor knocked on it, and, conversely, to knock after the assessor tapped. The total score reflected the percent correct across 16 test trials ($\alpha = 0.83$). The *Big/Little Game* (IC task, Carlson, 2005) assessed children's ability to state a contradictory rather than a salient perceptual feature of an image. Children were asked to say "little" when presented with a picture of a big cat and to say "big" when presented with a picture of a little cat. The total score reflected the percent correct across 16 test trials ($\alpha = 0.92$). The *Go/NoGo Game* (IC task) assessed children's ability to perform an action following a frequent "Go" stimulus and to inhibit that same action following a less frequent "NoGo" stimulus (Willoughby, Blair, Wirth, Greenberg, & The Family Life Project Investigators, 2010). Children were asked to press a desk bell when presented with an image of a cat and not to press the bell when presented with an image of a dog. The total score reflected the percentage of correct "NoGo" trials ($\alpha = 0.89$) for children who demonstrated at least 76% accuracy on "Go" trials. During the *Forward Word Span* (WM task), children were asked to repeat verbally presented word sequences of increasing length. The total score represented the longest span for which at least two test trials were repeated correctly, plus 0.5 if one longer sequence was correctly repeated at the next level (Noël, 2009). Children who could not repeat any words, or only one word, were given a score of 1 ($\alpha = 0.93$). The *Separated Dimensional Change Card Sort* (S-DCCS, CF task, Carlson, 2005) measured children's ability to switch attention between two different dimensions, using a set of colored cards (green or yellow) featuring the black silhouette of a common shape (star or truck). Children were asked to complete six color trials, and then, after a rule switch, six shape trials. The total score reflected the percentage of correct post-switch trials ($\alpha = 0.86$).

2.3.2 | Antecedent cognitive skills

Children's cognitive and language skills at 24 months were assessed using the Bayley Scales of Infant and Toddler Development, Third Edition (BSID-III; Bayley, 2006). Raw scores for the cognitive, receptive communication, and expressive communication subtests were calculated by summing the number of correct items. The cognitive ($M = 78.24$, $SD = 14.61$) and language ($M = 82.76$, $SD = 13.43$) composite scores were averaged to create a measure of *general cognitive skills* at 24 months ($M = 80.50$, $SD = 12.79$, $r = 0.66$).

2.3.3 | General intelligence

Children's intelligence at 48 months was assessed using the Wechsler Preschool and Primary Scale of Intelligence – III (WPPSI-III; Wechsler, 2002). Items were culturally adapted by replacing unfamiliar words and pictures with alternates that are more representative of the local community (see Rasheed et al., 2017 for adaptation details). A full scale comprising the Block Design, Matrix Reasoning, Picture Concepts, Information, Vocabulary, Word Reasoning, and Symbol Search scale scores was used as a composite measure of *general intelligence* at 48 months ($M = 75.56$, $SD = 7.56$, $\alpha = 0.91$).

2.3.4 | Socioeconomic factors at birth

Family wealth was assessed using 44 items that reflect ownership of property, livestock, and household assets (e.g., television, bicycle, car), dwelling characteristics (e.g., access to water, sanitation facilities, type of flooring material), and number of bedrooms in the home. Principal components analysis was used to generate a single standardized factor score that represents cumulative family wealth ($M = 0.00$, $SD = 0.99$). *Maternal education* was obtained by maternal report of the number of years the mother attended formal school ($M = 2.19$, $SD = 3.69$). Mothers reported on the *number of siblings* the target child had at birth ($M = 2.50$, $SD = 2.31$).

2.3.5 | Intervention exposure

Two binary variables were created to represent children's exposure to the RS intervention (1 = RS, 0 = no RS) and EN intervention

(1 = EN, 0 = no EN). Consistent with the 2 × 2 factorial design of the PEDS Trial and published evaluation studies (Yousafzai et al., 2014, 2016), we employed two binary variables to control for the main effects of the intervention exposure. The RS intervention was based on the adapted United Nations Children's Fund and World's Health Organization's Care for Child Development curriculum (UNICEF & WHO, 2011) and was administered by trained community health workers. Mothers received coaching, support, and feedback during monthly home visits and community meetings on how to be responsive and sensitive while engaging in developmentally appropriate play and communication activities (see Yousafzai et al., 2014 for details).

2.3.6 | Height-for-age and food insecurity

Trained assessors measured children's height to the nearest 0.1 cm in accordance with standardized guidelines (Cogill, 2003). Height was converted into a standardized height-for-age index (M = −2.33, SD = 1.12) using WHO Anthro software V3.2.2. Furthermore, we controlled for *family food insecurity* (Coates, Swindale, & Bilinsky, 2007) at 24 months, which was assessed using a binary measure of whether the family had access to safe and nutritionally adequate food (0 = food secure, 1 = food insecure; 32.74% were food insecure).

2.3.7 | Home stimulation quality

Home stimulation quality was measured using the adapted Home Observation for Measurement of the Environment Inventory (HOME; Caldwell & Bradley, 1984), which has been used widely in LMIC (Aboud & Yousafzai, 2015). Items representing six dimensions (responsivity, acceptance, organization, learning materials, involvement, and variety) of the infant/toddler version and eight dimensions (responsivity, acceptance, language stimulation, learning materials, physical environment, academic stimulation, modeling, and variety) of the early childhood version were scored as absent or present, based on mothers' report of family living patterns and habits, observation of spontaneous mother–child interactions, and orderliness and enrichment potential of the physical home environment (see Obradović, Yousafzai, et al., 2016 for lists of all items and adaptation procedures). A final score was generated by summing all 45 items at 18 months (M = 30.81, SD = 5.44, α = 0.82) and 54 items at 48 months (M = 32.07, SD = 6.74, α = 0.94).

2.3.8 | Maternal scaffolding

Maternal scaffolding behaviors were observed during a 5-min interaction in which mothers were instructed to play with their children using a picture book. They were rated using the Observation of Mother and Child Interaction protocol (see Rasheed & Yousafzai, 2015 for details). Scoring was based on the frequency of the observed behavior, with a higher score denoting more frequent demonstration of behaviors (0 = never, 1 = very few, one to two times, 2 = sometimes, three to four times, 3 = often, five or more times). A *maternal scaffolding at 24 months* (M = 1.602, SD = 0.804, α = 0.86) score was created by averaging six ratings of maternal behaviors: (a) sensitivity and contingent responding; (b) scaffolding by expanding on the child's speech; (c) pointing and naming objects in the book; (d) posing questions to the child; (e) responding to the child's questions or requests; and (f) helping the child maintain interest. *Maternal scaffolding at 48 months* (M = 1.408, SD = 0.745, α = 0.67) was created by averaging four ratings: (a) sensitivity and contingent responding; (b) scaffolding by expanding on the child's speech; (c) posing simple and complex questions to the child; and (d) helping the child to focus and maintain interest.

2.3.9 | Maternal cognitive skills

The vocabulary subtest of the Wechsler Abbreviated Scales of Intelligence (WASI-II; Wechsler, 2011) was used as a measure of *maternal verbal intelligence*. The subtest was deemed culturally relevant after expert review and two rounds of piloting. A raw score based on 31 items that measure word knowledge and verbal concept formation through picture and verbal items was converted to a t-score. The *Forward Word Span* task, which requires repeating a sequence of words delivered by the assessor in the same order, was used as a measure of maternal short-term memory. The *Backward Word Span* task, which requires repeating a sequence of words delivered by the assessor in reverse order, was used as a measure of maternal working memory. For both span tasks, final scores were calculated using the longest span for which at least two test trials were repeated correctly, plus 0.5 if a sequence was correctly repeated at the next level (Noël, 2009).

2.4 | Missing data

The percentage of missing data was small, ranging from 0.00% to 7.68%, except for the child EF composite (12.14%) and maternal working memory measure (19.43%), which was largely due to an inability to understand task rules. Other reasons for missing data included external disruptions that caused the assessment to be cut short (e.g., no electricity in the room), lack of permission from the head of household to stay for the full duration, challenging behavior, and obvious disabilities (e.g., unable to walk or speak). Missing data on all independent variables were multiply imputed using chained equations with 20 datasets.

2.5 | Data analytic plan

Main analyses were conducted in Stata Version 13.1 (StataCorp, 2013). We examined the underlying structure of the EF construct using confirmatory factor analyses that compared nested one-factor and two-factor models. We analyzed how antecedent and concurrent child and family factors related to EFs using a series of five hierarchical regression models of increasing complexity. To account for clustering of children within the 80 Lady Health Workers who administered the original intervention trial, we used robust clustered standard errors.

We tested the significance of indirect effect pathways using Stata's seemingly unrelated regression (*sureg*) command, which estimates a series of nested regression models and allows for cross-equation error correlation. Indirect effects and standard errors were calculated using the product of the coefficients method (Baron & Kenny, 1986). When indirect effects were found for pathways that had non-significant direct effects, we calculated the power to detect significant direct and indirect effects with the R package *PowMedR*, which uses the joint-significance approach as described in Kenny and Judd (2014).

3 | RESULTS

3.1 | EF tasks

We created six binary filter variables that reflected children's performance on the practice trials using task-specific comprehension criteria (0 = did not pass criteria; 1 = passed criteria). If children did not pass comprehension criteria, we did not use their performance score on that task to create the final EF composite score. This ensured that performance on test trials more accurately measured EFs rather than children's ability to understand the task rules (i.e., general intelligence) or other task-specific factors. The rate of comprehension ranged from 80.1% to 91.3% across EF tasks, with the exception that only 47% of children passed both the color/shape practice trials and the pre-switch test trials of the S-DCCS task. Please see Appendix C for a detailed description and evaluation of comprehension criteria and performance variables for each individual EF task as well as task-level correlations.

3.2 | EF composite

Recent research has shown that while a full EF battery is preferred, data from a three-task battery provide an acceptable measure of children's overall EF performance when there are study constraints or data collection challenges (Willoughby et al., 2013). To produce an inclusive, but still reliable measure of overall EF performance, we calculated a composite score only for children (N = 1,144) who had valid test scores on *at least* three of the six tasks (see Appendix C for more information). Children with at least three valid EF scores were from households with significantly more wealth at baseline ($t(1476) = -2.327$, $p = 0.020$) compared to children who were enrolled in the PEDS trial and did not have valid EF scores due to attrition or a lack of EF task comprehension. There were no significant differences between those two groups on maternal education or number of siblings at baseline.

We conducted a confirmatory factor analysis to ensure that performances on different EF tasks represent the same underlying construct, as has been reported in preschoolers from HIC (Wiebe, Espy, & Charak, 2008), before creating a single composite score. The one-factor solution showed good absolute model fit (CFI = 0.986, TLI = 0.976, RMSEA = 0.023). All six tasks loaded onto one factor, with standardized loadings ranging from 0.40 to 0.56. The relative fit of this factor solution was further tested against a two-factor model that separated the four IC tasks from more developmentally advanced WM and CF tasks. The two-factor model did not fit the data better than the single-factor model ($\Delta\chi^2(1) = 0.20$, $p = 0.652$). We created a composite score by standardizing and averaging the six EF performance scores ($\alpha = 0.61$, $M = -0.03$, $SD = 0.61$). Our tasks had relatively low bivariate correlations (see Appendix C, Table C3), and a significant vanishing tetrad test chi-square statistic ($\chi^2(45) = 119.74$, $p = 0.002$) provided support for an averaged composite that equally weights each task (Willoughby, Holochwost, Blanton, & Blair, 2014). The EF composite had a relatively normal distribution (skewness = 0.182, kurtosis = 2.773), which is graphically represented in the Appendix.

Bivariate correlations revealed expected associations of EFs with the child and family factors (see Table 1). The correlation between the general cognitive skills at 24 and 48 months ($r = 0.39$, $p < 0.001$) was significantly higher ($z = 3.56$, $p < 0.001$) than the correlation between cognitive skills at 24 months and EFs at 48 months ($r = 0.29$, $p < 0.001$).

3.3 | Regression analysis: Developmental antecedents and correlates of preschoolers' EFs

Regression results are presented in Table 2. *Model 1* included the child's gender, socioeconomic factors at birth (family wealth, maternal education, number of siblings), RS and EN intervention effects, targeted family factors assessed during the second year of the child's life (home stimulation and maternal scaffolding), as well as food insecurity and height-for-age at 24 months. We conceived of this model as a baseline model reflecting findings that have been published elsewhere (Obradović, Yousafzai, et al., 2016). Significant predictors of preschool EFs included maternal education, number of siblings at baseline, maternal scaffolding behaviors at 24 months, children's height-for-age at 24 months, and the RS intervention.

Model 2 extended previous work by showing that children's cognitive skills at 24 months emerged as a unique longitudinal predictor of EFs at 48 months ($\beta = 0.179$, $p < 0.001$), explaining significant additional variance in EFs ($\Delta R^2 = 0.018$; $F(1, 76.7) = 23.85$, $p < 0.001$). Inclusion of this predictor shed new light on mediating processes during the first 2 years of life. First, cognitive skills at 24 months partially mediated the effect of the RS intervention exposure on preschoolers' EFs (indirect effect: $B = 0.020$, $p = 0.001$, 24.09% of the total effect). Second, cognitive skills at 24 months mediated the association between height-for-age at 24 months and EFs at 48 months (indirect effect: $B = 0.039$, $p < 0.001$, 21.93% of the total effect) as well as the association between maternal scaffolding at 24 months and preschoolers' EFs (indirect effect: $B = 0.069$, $p < 0.001$, 65.69% of the total effect). Third, cognitive skills at 24 months also mediated the association between home stimulation quality at 18 months on preschoolers' EFs (indirect effect: $B = 0.022$, $p = 0.001$), even though home stimulation quality was not a significant predictor of EFs. We had low power to detect the association of home stimulation quality

TABLE 1 Descriptive statistics and zero-order correlations between predictor variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1. Male	–																	
2. Wealth (b)	−0.01	–																
3. Mat educ (b)	0.02	0.37***	–															
4. Num sib (b)	0.00	−0.12***	−0.16***	–														
5. Food ins (24 m)	0.04	−0.25***	−0.22***	0.12***	–													
6. HOME (18 m)	−0.03	0.30***	0.28***	−0.16***	−0.24***	–												
7. Scaff (24 m)	−0.01	0.20***	0.20***	−0.05	−0.15***	0.37***	–											
8. Height (24 m)	−0.02	0.27***	0.23***	−0.10***	−0.17***	0.23***	0.16***	–										
9. RS	0.03	0.04	−0.01	0.02	−0.07*	0.39***	0.30***	−0.04	–									
10. EN	−0.05	−0.01	0.09**	−0.03	−0.14***	0.10***	0.13***	0.03	−0.01	–								
11. Cog (24 m)	0.01	0.25***	0.21***	−0.12***	−0.22***	0.42***	0.52***	0.35***	0.28***	0.09**	–							
12. HOME (48 m)	−0.01	0.31***	0.34***	−0.02	−0.24***	0.46***	0.31***	0.24***	0.09**	0.13***	0.36***	–						
13. Scaff (48 m)	0.03	0.17***	0.29***	−0.06*	−0.11***	0.28***	0.28***	0.12***	0.13***	0.03	0.22***	0.31***	–					
14. Mat IQ	0.03	0.32***	0.42***	−0.05	−0.21***	0.32***	0.28***	0.17***	0.13***	0.05	0.24***	0.39***	0.29***	–				
15. Mat FWS	−0.03	0.19***	0.34***	−0.10***	−0.15***	0.18***	0.14***	0.15***	0.04	0.00	0.16***	0.21***	0.20***	0.32***	–			
16. Mat BWS	−0.02	0.18***	0.41***	−0.06	−0.15***	0.20***	0.21***	0.13***	0.10**	0.05	0.18***	0.18***	0.17***	0.29***	0.34***	–		
17. Child IQ	0.05	0.21***	0.22***	−0.06*	−0.16***	0.26***	0.24***	0.28***	0.11***	−0.03	0.38***	0.32***	0.23***	0.39***	0.21***	0.19***	–	
18. Child EFs	−0.01	0.14***	0.18***	0.02	−0.12***	0.19***	0.20***	0.23***	0.13***	0.01	0.29***	0.23***	0.20***	0.28***	0.18***	0.17***	0.55***	–
Mean/%	54%	−0.002	2.192	2.500	33%	30.811	1.602	−2.333	51%	48%	80.500	32.071	1.408	22.497	3.608	2.393	−0.027	−0.027
SD		0.988	3.686	2.309		5.444	0.804	1.123			12.793	6.741	0.745	3.777	0.853	0.747	0.611	0.611
N	1,302	1,294	1,302	1,267	1,301	1,273	1,301	1,278	1,302	1,302	1,298	1,295	1,289	1,202	1,254	1,049	1,144	1,144

Notes. b = baseline; m = months; mat educ = maternal education; num sib = number of siblings; food ins = food insecurity; HOME = home stimulation quality; scaff = maternal scaffolding; height = height-for-age; RS = responsive stimulation intervention; EN = enhanced nutrition intervention; cog = child cognitive skills; mat IQ = maternal intelligence; mat FWS = maternal Forward Word Span; mat BWS = maternal Backward Word span; IQ = intelligence; EFs = executive functions.

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

TABLE 2 Stepwise regression models predicting EF skills from family factors and developmental correlates

	Model 1	Model 2	Model 3	Model 4	Model 5
	β (SE)	*β (SE)*	*β (SE)*	*β (SE)*	*β (SE)*
Male	−0.010 (0.029)	−0.014 (0.028)	−0.018 (0.027)	−0.021 (0.026)	−0.030 (0.024)
Wealth (b)	0.005 (0.031)	−0.004 (0.031)	−0.013 (0.030)	−0.034 (0.031)	−0.027 (0.027)
Maternal education (b)	0.108 (0.033)**	0.106 (0.033)**	0.071 (0.034)*	0.003 (0.035)	0.023 (0.035)
Number of siblings (b)	0.070 (0.032)*	0.077 (0.031)*	0.067 (0.032)*	0.063 (0.031)*	0.065 (0.027)*
Food insecurity (24 m)	−0.044 (0.026)	−0.036 (0.025)	−0.028 (0.025)	−0.018 (0.025)	−0.009 (0.022)
HOME quality (18 m)	0.047 (0.040)	0.024 (0.039)	−0.021 (0.041)	−0.030 (0.042)	−0.029 (0.036)
Maternal scaffolding (24 m)	0.105 (0.027)***	0.035 (0.029)	0.010 (0.029)	−0.011 (0.029)	0.008 (0.027)
Height-for-age (24 m)	0.182 (0.031)***	0.142 (0.032)***	0.142 (0.032)***	0.133 (0.032)***	0.079 (0.027)**
Responsive stimulation (RS)	0.084 (0.027)**	0.063 (0.027)*	0.073 (0.028)*	0.065 (0.027)*	0.062 (0.025)*
Enhanced nutrition (EN)	−0.022 (0.027)	−0.026 (0.027)	−0.031 (0.027)	−0.031 (0.026)	0.007 (0.023)
Child cognitive skills (24 m)		0.179 (0.036)***	0.165 (0.035)***	0.169 (0.035)***	0.052 (0.033)
HOME quality (48 m)			0.089 (0.037)*	0.060 (0.037)	0.009 (0.033)
Maternal scaffolding (48 m)			0.098 (0.032)**	0.079 (0.031)*	0.052 (0.029)
Maternal verbal IQ				0.145 (0.035)***	0.034 (0.032)
Maternal FWS				0.065 (0.029)*	0.049 (0.026)
Maternal BWS				0.039 (0.029)	0.022 (0.027)
Child IQ (48 m)					0.464 (0.030)***
Constant	−0.015 (0.027)	−0.022 (0.026)	−0.025 (0.026)	−0.029 (0.025)	−0.050 (0.022)*
N	1,144	1,144	1,144	1,144	1,144
R^2	0.102	0.120	0.134	0.157	0.318

All models use robust standard errors, clustered at the Lady Health Worker level. b = baseline; m = months; HOME = home stimulation; EFs = executive functions; FWS = Forward Word Span; BWS = Backward Word Span.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

at 18 months with EFs at 48 months (30.0% power, $\alpha = 0.05$) and high power to detect the indirect mediation pathway (99.0% power, $\alpha = 0.05$; Kenny & Judd, 2014). These indirect effects are presented graphically in Figure 1a.

Model 3 added concurrent measures of home stimulation quality and maternal scaffolding at 48 months, which explained significant additional variance in EFs ($\Delta R^2 = 0.014$; $F(2, 77) = 9.25$, $p < 0.001$). Consistent with previously published findings (Obradović, Yousafzai, et al., 2016), both aspects of concurrent family enrichment uniquely contributed to preschoolers' EFs, even with the inclusion of an antecedent measure of cognitive skills at 24 months. All indirect effects for Models 2 and 3 are presented in Appendix Table D1.

Model 4 extended previous work by showing how three maternal cognitive skills (verbal intelligence, short-term memory, and working memory) relate to children's EFs. Maternal verbal intelligence and short-term memory emerged as unique predictors of preschoolers' EFs ($\beta = 0.145$, $p < 0.001$; $\beta = 0.065$, $p = 0.026$, respectively), explaining significant additional variance in EFs ($\Delta R^2 = 0.023$; $F(3, 74.6) = 11.70$, $p < 0.001$). The relation between maternal education and EFs was no longer significant, as it was fully mediated by maternal verbal intelligence (indirect effect: $B = 0.029$, $p < 0.001$, 98.17% of the total effect). Maternal verbal intelligence also mediated the association between wealth and EFs ($B = 0.019$, $p = 0.006$) and maternal scaffolding at 24 months and EFs (indirect effect: $B = 0.015$, $p = 0.020$), even though wealth and maternal scaffolding at 24 months were not significant predictors of EFs due to power issues (direct effect power: 21.2% for wealth; 6.8% for scaffolding; indirect effect power: 98.6% for wealth, 91.9% for scaffolding; $\alpha = 0.05$). The association between concurrent home stimulation quality and EFs was mediated by maternal verbal intelligence (indirect effect: $B = 0.027$, $p = 0.001$, 31.58% of the total effect) and rendered non-significant. In contrast, the link between concurrent maternal scaffolding and EFs continued to be significant, but it was reduced in magnitude ($\beta = 0.077$, $p = 0.014$) and partially mediated by maternal verbal intelligence (indirect effect: $B = 0.010$, $p = 0.045$, 12.02% of the total effect). These indirect effects are presented graphically in Figure 1b.

Model 5 extended previous work by showing that a concurrent measure of children's general intelligence emerged as a strong unique predictor of EFs above and beyond all other covariates ($\beta = 0.464$, $p < 0.001$), explaining significant additional variance in EFs ($\Delta R^2 = 0.161$; $F(1, 75.4) = 234.26$, $p < 0.001$). After accounting

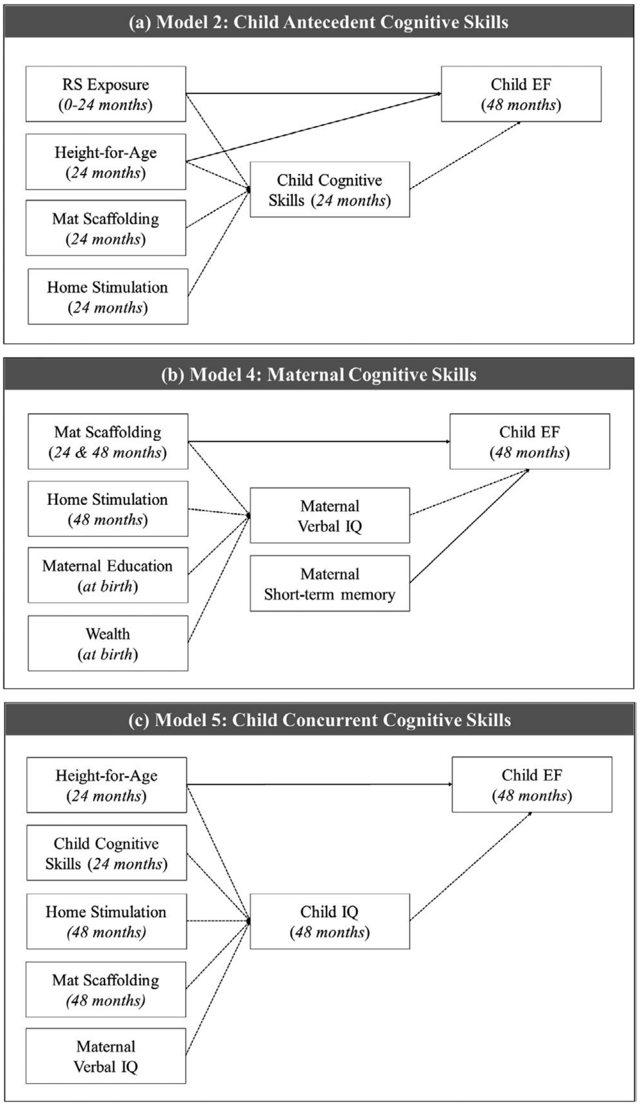

FIGURE 1 Significant indirect effects for (a) Model 2, (b) Model 4, and (c) Model 5. Note that significant direct effects are not shown. In Model 2, maternal education and number of siblings have significant direct effects on EFs. In Model 4, number of siblings, height-for-age (24 months), the responsive stimulation intervention, and child cognitive skills (24 months) have direct effects on EFs. In Model 5, number of siblings and the responsive stimulation intervention have direct effects on EFs

for the significant overlap with general intelligence (i.e., 30.25% of shared variance), the following variables remained significant predictors of preschoolers' EFs: number of older siblings ($\beta = 0.065$, $p = 0.020$), height-for-age at 24 months ($\beta = 0.079$, $p = 0.005$), and the RS intervention ($\beta = 0.062$, $p = 0.014$). The significant association between height-for-age at 24 months and EFs at 48 months was also partially mediated by general intelligence at 48 months (indirect effect: $B = 0.053$, $p < 0.001$). The longitudinal association between children's cognitive skills at 24 months and EFs at 48 months was mediated by children's general intelligence at 48 months (indirect effect: $B = 0.116$, $p < 0.001$, 69.84% of the total effect). Children's general intelligence at 48 months also mediated three concurrent associations between (a) maternal scaffolding and EFs (indirect effect: $B = 0.027$, $p = 0.040$, 35.75% of the total effect); (b) home stimulation quality and EFs (indirect effect: $B = 0.051$, $p = 0.001$; direct effect power: 6.4%; indirect effect power: 96.0%; $\alpha = 0.05$); and (c) maternal verbal intelligence and EFs (indirect effect: $B = 0.111$, $p < 0.001$, 74.96% of the total effect). These indirect effects are presented graphically in Figure 1c. All indirect effects for Models 4 and 5 are presented in Appendix Table D2.

4 | DISCUSSION

The goal of this study was to advance knowledge of factors that relate to EF development in highly disadvantaged preschoolers living in rural areas of LMIC. We adapted and tested a battery of standard EF tasks that can be used in similar settings to conduct a developmentally and culturally appropriate assessment of early EF skills that yields reliable and valid EF measures. Our work provided unique insights about the comprehension of EF tasks among disadvantaged LMIC preschoolers and revealed the unidimensional structure of an EF construct as indexed by six individual tasks. This longitudinal study is the first to: (a) demonstrate developmental continuity between general cognitive development at age two and emergent EFs at age four in a LMIC context; and (b) identify antecedent and concurrent family and maternal factors that predict preschoolers' EFs in a LMIC context, after accounting for the significant contribution of related, yet distinct cognitive skills at ages two and four. We demonstrated the unique importance of an early childhood parenting intervention and children's growth status at age two for preschoolers' EFs, after controlling for the contributions of children's general cognition at ages two and four. Our findings also revealed that maternal cognitive scaffolding behaviors and mothers' own cognitive capacities were independently associated with children's EFs. Finally, our results highlight that older siblings may play a unique role in promoting EFs in a LMIC context.

4.1 | Assessment of executive functioning in LMIC context

Many challenges arise when researchers employ tests developed and validated with children living in HIC to assess cognitive skills of children in LMIC (see Pitchford & Outhwaite, 2016; Zuilkowski, McCoy, Serpell, Matafwali, & Fink, 2016). We want to highlight three issues in conducting EF assessments with preschool children in rural LMIC settings at scale. First, we found it essential to work with local experts and complete additional rounds of pilot testing to produce culturally *and* developmentally appropriate tasks for young children who have not been exposed to any educational programming. For example, children in our sample struggled with fanciful colors and symbols (e.g., red rabbit) that are typically understood by older members of their community or by preschoolers in more advantaged settings. Second, we found it necessary to address administration procedures that are typically not discussed as part of cross-cultural measurement adaptation. While most EF studies in the U.S. context are conducted by a small number of highly trained research assistants, field research teams in LMIC are often larger and more heterogeneous in terms of their education, experience working with children, and familiarity with psychological assessments. In order to maintain high-quality data collection across a large sample and large assessment team, we standardized (a) assessment protocols; (b) explicit guidelines for dealing with assessment challenges (e.g., non-compliance, inaudible response); and (c) assessors' feedback across six EF tasks that were originally independently developed. Third, we evaluated children's comprehension of EF task instructions by examining performance on practice trials. Although it is common to exclude children who appear not to understand task rules, extant EF studies rarely report explicit exclusion or comprehension criteria or how these assessment decisions affect their analytic sample and strategy. We hope future studies follow our lead in using performance on practice trials to post hoc evaluate children's comprehension rather than rely on field assessors to make this complex decision during the assessment.

Although no task can purely measure a single EF component, the majority of children in our study understood the tasks designed to primarily assess motoric and verbal response inhibition and suppression of visual interference. Performance on a task designed to assess a developmentally more advanced EF skill of cognitive flexibility (Diamond, 2013) proved more challenging. Our analyses confirmed that all six performance variables loaded on a single latent factor. This is consistent with the EF structure observed in preschoolers from the United States and the argument that the tasks designed to assess conceptually distinct EF dimensions in early childhood actually measure a unitary cognitive ability despite their superficial differences (Wiebe et al., 2008). In accordance with these results and following recent methodological recommendations (Willoughby et al., 2013, 2014), we used an aggregate index of EFs to measure overall EF more reliably than any individual EF task. However, we advocate for continued investigation and report of comprehension and performance on individual EF tasks as a way to improve the reliability and validity of EF assessments in LMIC settings.

4.2 | Antecedent cognitive development and preschoolers' EFs in LMIC

Until recently, developmental researchers studying young children in LMIC have primarily focused on measuring general cognitive skills (Aboud & Yousafzai, 2015). Given the growing interest in directly assessing children's EFs in LMIC (Obradović, Yousafzai, et al., 2016; Oluwole, Noll, Winger, Akinyanju, & Novelli, 2016; Pitchford & Outhwaite, 2016; Wolf & McCoy, 2017), it is important to understand how antecedent cognitive skills relate to emergent EFs. Using the widely employed Bayley Scales of Infant and Toddler Development, we found that direct assessments of general cognitive skills at 24 months were significantly related to children's performance on EF tasks at 48 months. Furthermore, we found evidence of divergent validity: the association between general cognitive skills at ages two and four was significantly stronger than the association between cognitive skills at age two and EFs at age four.

Moreover, measures of cognitive development at age two explained how the antecedent child and family factors were linked to EFs. The effect of the responsive stimulation intervention on preschoolers' EFs was partially mediated by children's cognitive skills at the completion of the PEDS Trial (Obradović, Yousafzai, et al., 2016). The longitudinal associations of the factors that were targeted by the PEDS Trial (i.e., physical linear growth, quality of home stimulation, and maternal scaffolding during the second year of the child's life) with preschoolers' EF were also mediated by cognitive skills at age two. These findings highlight the need to account for developmental continuity of cognitive skills in order to identify how and when early parenting programs contribute to EF development in LMIC contexts. Knowing that the targeted familial stimulation practices affected preschoolers' EFs by increasing general cognitive skills at the conclusion of the intervention program can improve the design of future interventions and follow-up booster sessions aimed at fostering EFs. Many early childhood stimulation curricula in LMIC that focus on increasing parental sensitivity and responsiveness through play and communication activities in the first 2 years of life could be expanded to help parents adapt these skills to later stages of development and to engage in activities that promote preschoolers' learning and self-regulation. Specifically, parents can be supported in engaging young children in routines, chores, and games that require planning, setting goals, following rules, monitoring progress, turn-taking, collaborating, or responding flexibly, as a way to scaffold children's EFs.

4.3 | Home stimulation, maternal scaffolding, and maternal cognitive skills

This study identified proximal family level processes that are uniquely related to EFs in preschoolers living in highly disadvantaged, rural areas of LMIC, while accounting for more commonly studied distal factors like family wealth and maternal education (Fernald et al., 2011; Prado et al., 2010; Schady, 2011). We found that concurrent associations of the home stimulation quality and maternal scaffolding with EFs at age four (Obradović, Yousafzai, et al., 2016) were robust to controlling for antecedent cognitive skills at age two. Exposure to higher levels of cognitive stimulation at home appears to play a critical role in promoting cognitive development of preschool-age children who live in rural LMIC areas, where access to formal early educational opportunities is limited and where the quality of existing programs is low (UNICEF, 2013).

Next, we examined whether maternal cognitive skills are linked to children's EFs in LMIC, parallel to what has been recently shown in HIC samples (Cuevas et al., 2014; Deater-Deckard & Sturge-Apple, 2017). Indeed, both maternal verbal intelligence and maternal short-term memory independently predicted preschoolers' EFs, controlling for children's antecedent cognitive skills and physical growth. Furthermore, we found that maternal verbal intelligence fully mediated the association of maternal education with children's EFs, underscoring the importance of employing direct cognitive assessments when investigating variability in cognitive capacities among poor women with very little or no formal education. Programs designed to improve child development outcomes in rural LMIC areas should explicitly support the growth of maternal cognitive and literacy skills.

As more researchers turn to identifying specific, modifiable parental behaviors that are linked to children's cognitive development in LMIC (McCoy et al., 2015; Obradović, Yousafzai, et al., 2016), it is important to understand whether the associations between parenting behaviors and EFs are significant controlling for parental cognitive capacities (Crandall, Deater-Deckard, & Riley, 2015). For example, the relation between concurrent home stimulation quality and EFs was fully mediated by maternal verbal intelligence, whereas concurrent maternal scaffolding remained a significant predictor of EFs. We can assume that maternal verbal intelligence partially captures shared mother–child genetic endowment and socioeconomic resources (e.g., maternal verbal intelligence also explained the link between family wealth at birth and preschooler's EFs). Thus, this study provides additional evidence that targeting maternal scaffolding behaviors with parenting interventions is an effective way to promote early cognitive development in LMIC children, irrespective of maternal intelligence and family wealth. Future research should continue to examine how different maternal cognitive skills may affect child development in LMIC vis-à-vis parenting practices and uptake of intervention messages.

4.4 | Shared variance with IQ and unique EF predictors

As higher-order cognitive skills, EFs are linked to general cognitive capacities. Indeed, among preschoolers living in rural areas of LMIC, we found that 30% of the variance in EFs was shared with the concurrent measure of general intelligence, as indexed by a gold-standard direct assessment that has been locally validated (Rasheed et al., 2017). This finding corroborates the notion that EF and IQ skills are related, yet distinct constructs in LMIC preschoolers. As such, it is important to identify factors that relate to emerging EFs in LMIC context, beyond their associations with children's general intelligence. To extend recent LMIC studies that have examined children's EFs and cognition as separate outcomes (McCoy et al., 2015; Obradović, Yousafzai, et al., 2016), we modeled general cognitive skills as a predictor of EFs.

Not surprisingly, children's intelligence at age four fully explained the longitudinal association of antecedent cognitive skills at age two with preschoolers' EFs; however, it only partially explained the link between antecedent physical growth and EFs. Our study demonstrated that children's height-for-age at 24 months, an index of physical linear growth, is an important unique predictor of preschooler's EFs in rural LMIC settings. Physical growth status at age two can reflect early malnutrition (i.e., a height-for-age score below 2*SD* marks growth retardation, known as stunting, which can result from prenatal or postnatal chronic undernutrition) that may be particularly relevant for healthy neurocognitive development (Walker et al., 2011).

We also found that a measure of children's general intelligence fully explained the concurrent associations of preschoolers' EFs with maternal verbal intelligence, the quality of home stimulation, and maternal scaffolding. It is possible that these three variables reflect shared genetic endowment and enrichment opportunities that promote general cognitive development, and not specifically EFs. However, it is important to note that our observed measure of maternal scaffolding primarily focused on language stimulation (e.g., naming objects, expanding on the child's speech, posing questions, and responding to the child's questions). It is possible that mothers engaged in other everyday parenting practices that directly promoted children's EFs, but were not captured by our measure of maternal scaffolding.

Indeed, participation in an early responsive stimulation intervention targeting maternal knowledge and practices during the first 2 years of life was a unique predictor of EFs at age four, despite the inclusion of many significant child and family level predictors and mediators. Given the relevance of EFs for self-regulated behavior and learning (Jones, Barnes, Bailey, & Doolittle, 2017), future parenting intervention studies should identify and bolster specific components that uniquely promote preschoolers' EFs (e.g., teaching children how to stay focused, control impulsive behaviors, and cope with negative emotions during chores, routines, and play). At the same time, there is a need to develop developmentally appropriate and culturally sensitive observational measures of parenting behaviors that go beyond scaffolding of language and attention to capture parenting practices and family routines that foster young children's inhibitory control, working memory, and cognitive scaffolding.

Interestingly, the number of older siblings was also a unique positive predictor of EFs in this context. Relationship dynamics in larger families may demand greater self-regulation in children and thus offer more opportunities to practice and apply EFs. On the other hand, older siblings are known to provide additional caregiving support and may engage in dyadic co-regulation with the younger child. Positive parent–child co-regulation, as indexed by moment-to-moment changes in the child's and parent's regulation of attention and affect, has been shown to predict young children's self-regulation skills in HIC (Bardack, Herbers, & Obradović, 2017). Scalable and pragmatic approaches to measuring dynamic aspects of familial interactions will be crucial to understanding the roles that other caregivers play in promoting children's self-regulation in LMIC.

4.5 | Limitations and future directions

Although this study advances knowledge of EFs in disadvantaged preschoolers in a LMIC setting, it has several limitations. First, while the sample is large and representative of Pakistani children living in rural areas, the participants' experiences may differ from other LMIC children, particularly children in urban settings who often have greater exposure to educational opportunities. Second, longitudinal EF measurement would have enabled us to examine how proximal and distal factors contribute to growth and change in EF skills, a critical question for future EF research in LMIC. Third, our battery of EF tasks could be expanded to include more measures of working memory and cognitive flexibility, which would enable a rigorous examination of underlying EF factor structure and its changes over time in LMIC settings. Fourth, our choice of family processes was theory-driven, but it was not an exhaustive selection. Future studies should investigate the role of fathers (e.g., Meuwissen & Carlson, 2015) and other significant caregivers for preschoolers' EF development in LMIC, in order to identify the most promising targets for intervention. Finally, the current findings need to be extended by identifying the relative contribution of EFs and other cognitive measures for subsequent developmental (e.g., prosocial behaviors, peer relationships) and educational (e.g., school engagement, academic achievement) outcomes of children in LMIC in order to more fully understand the importance of early EFs for adaptation and resilience in this highly disadvantaged population of children.

5 | CONCLUSION

This study offers a play-based battery of EF tasks along with adaptation guidelines that can be implemented in other LMIC. Increased consistency in assessment of early EFs across LMIC studies will enable cross-cultural comparisons of EF development and advance our understanding of how these skills contribute to the development of children around the world. Using multi-method, multi-informant longitudinal data and a rigorous research design, this study sheds new light on the developmental timing and independent contributions of child and family factors from birth to age four for preschoolers' EFs in LMIC. Although our findings echo research conducted with at-risk children in HIC, children in LMIC face more extreme levels of chronic adversity and have poorer access to services and programs that can ameliorate those risks. The modest amount of variance in EFs that is explained by traditional child and family factors in our study reinforces the critical need to identify other processes that shape development of early EFs in highly disadvantaged LMIC contexts.

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