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RESEARCH ARTICLE

The unique relevance of executive functions and self-regulation behaviors for understanding early childhood experiences and preschoolers' outcomes in rural Pakistan

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Abstract

Performance-based measures of children's executive functions (EFs) do not capture children's application of these skills during everyday emotionally-laden and socially-mediated interactions. The current study demonstrates the value of using assessor report of self-regulation behaviors (inhibitory control and positive affect/engagement) in addition to EF tasks when studying early childhood experiences and development in a rural lower-middle-income country setting. In a sample of 1302 disadvantaged 4-year-olds living in rural Pakistan, we found that directly assessed EFs were significantly related to assessor observations of children's inhibitory control and positive affect/engagement during a structured assessment protocol. However, EFs and two types of self-regulation behaviors demonstrated unique associations with children's (1) *contextual experiences*, as indexed by family socio-economic resources, participation in parenting interventions, and children's physical growth; and (2) *age-salient developmental outcomes*, as indexed by direct assessment of pre-academic skills and maternal report of prosocial behaviors and behavior problems. First, family wealth uniquely predicted only observed positive affect/engagement, whereas maternal education uniquely predicted only EFs. Second, children's antecedent linear growth was a significant predictor of both EFs and positive affect/engagement, but exposure to an enhanced nutrition intervention during the first 2 years of life and preschoolers' hair cortisol concentration were associated only with observed self-regulation behaviors. Finally, both EFs and observed positive affect/engagement uniquely predicted children's pre-academic skills. In contrast, only assessors' ratings of positive affect/engagement uniquely predicted maternal report of prosocial behaviors and only assessors' ratings of inhibitory control uniquely predicted maternal report of behavioral problems.

KEYWORDS
executive function, low-and-middle-income countries, pre-academic skills, preschoolers, self-regulation, socio-emotional behavior

1 | INTRODUCTION

Executive functions (EFs) are a set of higher-order cognitive skills that enable children to control impulses, ignore distractions, mentally manipulate information, and flexibly shift between competing rules. They have been conceptualized and studied as building blocks of self-regulatory processes and goal-directed behaviors (Diamond, 2013; Obradović, 2016). Accordingly, direct assessments of young children's EFs are linked to their academic achievement and socio-emotional behaviors (Obradović et al., 2012; Zelazo et al., 2016). However, performance-based measures of children's EFs do not capture children's application of these skills during everyday emotionally-laden and socially-mediated interactions. Indeed, questionnaire-based measures of self-regulation behaviors explain important variability in young children's social-emotional and academic outcomes (Blair & Raver, 2015; Eisenberg et al., 2011). Despite global interest in understanding how EFs and self-regulation relate to experiences and adaptation in early childhood (Haslam et al., 2019; Obradović & Willoughby, 2019), empirical studies that examine both EFs and self-regulation behaviors in young children from low-and-middle-income countries (LMICs) are lacking. To advance our understanding of the unique relevance of cognitive and behavioral control for young children growing up in disadvantaged, rural LMIC settings, it is important that studies employ measures of both processes to (1) investigate how young children's directly assessed EFs relate to observations of their self-regulation behaviors; (2) identify how contextual experiences in early childhood and relevant stress physiology uniquely relate to EFs and self-regulation behaviors; and (3) test the independent associations of EFs and self-regulation behaviors with key developmental outcomes that are relevant for school readiness (e.g., social-emotional behaviors and pre-academic skills). This work aims to contribute to the global efforts to identify and assess preschool outcomes that support both learning and relationship goals within the Nurturing Care Framework (Black et al., 2021). Assessment of learning-relevant preschool skills is also critical to evaluating progress towards achieving the Sustainable Development Goals that focus on providing high-quality early childhood care and education opportunities for all children (Britto et al., 2017; Richter et al., 2017).

1.1 | Distinct aspects of EFs and self-regulation behaviors

Direct assessment of EFs via standardized performance tasks has many methodological advantages, including established neurodevelopmental correlates, strong psychometric properties, and a nuanced measurement of individual differences and longitudinal change (Diamond, 2013; Fiske & Holmboe, 2019; McCoy, 2019; Zelazo et al., 2016). Moreover, a growing body of research shows that directly assessed EFs of young children in LMICs show associations with biological covariates, contextual factors, and developmental outcomes that are similar to assessments of children in high-income countries (HICs; Obradović & Willoughby, 2019). With recent advances in scaling direct assessments through tablet-based EF tasks (Obradović & Steyer, 2022; Obradović & Willoughby, 2019), developmental psychologists are rapidly expanding our understanding of how these skills develop and support adaptation in young children around the globe. However, performance-based measures of EFs do not capture how children apply these skills during everyday tasks and interactions.

In early childhood, caregivers and teachers can provide a complementary perspective on children's contextualized self-regulation by observing and rating relevant behaviors. The modest convergence between performance-based measures of EFs and questionnaire-based measures of self-regulation behaviors suggest that these two assessment approaches capture related, yet distinct, aspects of cognitive and behavioral control. EF tasks are seen as capturing optimal performance, whereas behavioral ratings reflect typical, day-to-day performance (Toplak et al., 2013). However, since questionnaire ratings rely on adult judgment of children's behavior, these ratings may reflect various observer biases. For example, teacher reports of self-regulation have been shown to systematically vary according to children's demographic characteristics, appearance, and overall adjustment in other domains (e.g., Brandmiller et al., 2020; Fitzpatrick et al., 2016; Garcia et al., 2019), and caregiver reports can be influenced by the adult's own well-being (e.g., Joyner et al., 2009; Silver, 2014). At the same time, children's performance on EF tasks is never independent of their subjective experience of the assessment procedures, so EF tasks should not be considered an objective assessment (Obradović & Steyer, 2022). For these reasons, performance-based tasks and questionnaire-based behavioral ratings should be used together to yield a more complete understanding of regulatory processes in young children.

In rural LMIC settings, it may not be feasible to acquire teacher reports of young children's behavior, given limited access to early education programs and poor attendance rates (McCoy et al., 2018).

RESEARCH HIGHLIGHTS

- Direct assessment of executive function skills was significantly related to assessor observations of young children's inhibitory control and self-regulation of positive affect and engagement.
- Children's antecedent linear growth was linked to both executive function skills and positive affect/engagement, whereas family wealth and nutrition intervention uniquely predicted only observed self-regulation.
- Higher levels of hair cortisol concentrations were related to greater levels of inhibitory control and positive affect/engagement in preschool girls, controlling for contextual covariates.
- Executive function skills and positive affect/engagement uniquely predicted preschoolers' pre-academic skills, but only assessors' observations uniquely predicted maternal report of prosocial behaviors and behavioral problems.

It can also be challenging to obtain reliable reports from caregivers, who tend to have low literacy skills and lack experience rating their children's behaviors on Likert scale questionnaires (Finch et al., 2018). Training research staff to observe and rate children's behaviors during a structured assessment protocol is a valid and pragmatic alternative to obtaining parent or teacher reports of children's self-regulation behaviors. The Preschool Self-Regulation Assessment-Assessor Report (PSRA-AR; Smith-Donald et al., 2007) has been developed to capture assessor observations of children's self-regulation behaviors, including their ability to ignore distractions, refrain from touching materials, and wait between tasks, as well as their engagement, cooperation, and affect. As such, PSRA-AR measures self-regulation behaviors that conceptually map onto the EF domain of inhibitory control (i.e., ability to control impulsive response and suppress attention to interfering information), in addition to regulation of children's affect and engagement during social interaction with the assessor (i.e., ability to stay alert and interactive, display active task mastery, display positive and control negative emotions).

The unique strength of PSRA-AR is that it contains specific descriptors of different behaviors as response options rather than abstract markers of the frequency or likelihood of a given behavior, which helps to constrain subjective interpretations. For example, when rating children's inhibitory control as indexed by their ability to refrain from indiscriminately touching test materials, assessors can choose these response options: (1) child shows self-restraint even with interesting tasks and does not begin tasks or surveys until told to; (2) child generally shows self-control but starts to touch or play with keyboard or survey once or twice during assessment; (3) child needs multiple reminders not to touch keyboard or survey materials, has hard time stopping when it's time; and (4) assessment often interrupted by child's difficulty with grabbing and touching materials. This feature of the PSRA-AR helps in training large assessment teams and in establishing reliability among observers who may lack extensive experience rating young children's behaviors.

In a large study of preschoolers from an urban public school district in the United States, Daneri et al. (2018) found that the PSRA-AR demonstrated full scalar invariance across economic risk, gender, and racial/ethnic groups. Different PSRA-AR composites comprising attention and impulse control items have shown modest-to-moderate associations with direct assessments of EFs in preschool and kindergarten samples in the United States (Daneri et al., 2018; Obradović & Finch, 2017; Obradović, Portilla, et al., 2016; Smith-Donald et al., 2007). In recent years, culturally adapted and shortened versions of PSRA-AR have been used in large studies of young children in LMICs (Ahmed et al., 2021; Aurino et al., 2020; Kim et al., 2020; McCoy et al., 2017; von Suchodoletz et al., 2015; Willoughby et al., 2019). A few studies of preschool-aged children in Kenya, Ghana, and Kosovo have replicated modest-to-moderate positive correlations of the varied PSRA-AR composites and direct measurements of EFs (Ahmed et al., 2021; von Suchodoletz et al., 2015; Willoughby et al., 2019). As more researchers consider this measurement approach, there is a need to better understand the convergence, contextual correlates, and predictive validity of assessor reports in comparison to direct assessments of EFs.

1.2 | Contextual covariates of EFs and self-regulation behaviors

Indices of socio-economic advantage, such as higher household income, family wealth, and parental education, have been consistently linked to better performance on EF tasks in preschoolers in many countries, including Cambodia, Ghana, Indonesia, Madagascar, Pakistan, the United States, and Zambia (Berkes et al., 2019; Fernald et al., 2011; Lawson et al., 2017; Lipina et al., 2013; McCoy et al., 2017; Obradović et al., 2019; Prado et al., 2010; Wolf & McCoy, 2017). Family socio-economic resources show analogous positive associations with teacher and parent reports of more optimal self-regulation behaviors (e.g., Evans & English, 2002; Mistry et al., 2004; Sektnan et al., 2010). One HIC study shows that in a community sample of kindergarteners, children from more advantageous economic backgrounds were observed to display greater self-regulation as rated on the PSRA-AR (Obradović, Portilla, et al., 2016). Given the potential for using PSRA-AR in LMIC studies to provide a complementary perspective on young children's self-regulation, it is important to know whether and how family socio-economic resources and parental education relate to assessors' observations of children's behavior.

Going beyond distal measures of family socio-economic status, researchers have identified a more proximal process by which family socio-economic resources may directly impact the development of emerging EFs and self-regulation in young children. Young children's nutritional experiences and associated physical growth represent a key pathway by which experiences of poverty may undermine cognitive development (Black et al., 2017; Grantham-McGregor et al., 2007). Specifically, household food security and children's height-for-age have emerged as significant and robust predictors of preschoolers' EFs in LMICs (e.g., Berkes et al., 2019; Black et al., 2019; Obradović et al., 2019). Household food insecurity has also been linked to lower kindergarten readiness skills, including measures of self-regulation, in the United States (Johnson & Markowitz, 2018; Nelson et al., 2016). Further, a recent study of primary school-aged children in Ghana showed that transitory experiences of food insecurity were related to lower PSRA-AR ratings of self-regulation behaviors as well as direct assessments of numeracy, literacy, and short-term memory (Aurino et al., 2020). More work is needed to understand how children's chronic undernutrition (often measured via height-for-age) and experiences of food insecurity, both uniquely relate to displays of self-regulation behaviors.

1.3 | Associations of stress physiology with EF skills and self-regulation behaviors

The stress hormone cortisol, a marker of activity in the hypothalamic–pituitary–adrenal axis (HPAA), has also been hypothesized as a key pathway by which contextual experiences of early adversity are biologically embedded in a way that undermines the development of self-regulation and EFs (Blair & Raver, 2012; Obradović & Armstrong-Carter, 2020). While elevated levels of baseline salivary cortisol have

been linked to lower cognitive performance and parent-reported self-regulation behaviors in preschoolers in the United States (Suor et al., 2015; Wagner et al., 2016), salivary cortisol measures provide limited insight into chronic activation of the HPAA. Thus, researchers have started investigating how hair cortisol concentrations (HCCs), which reflect a 3-month cumulative metric of cortisol output, relate to children's skills and behaviors (Bates et al., 2017; Gray et al., 2018).

In the United States, higher HCCs have been linked with parent and teacher reports of greater socio-emotional behavioral problems in infants and school-age children (Fuchs et al., 2018; Palmer et al., 2013). In the United Arab Emirates, higher HCCs have been associated with lower EFs in 5-year-old children (von Suchodoletz & Barza, 2015). By contrast, higher HCCs have also been associated with lower levels of ADHD symptoms in German kindergarten boys (Pauli-Pott et al., 2017). In a previous study using a subsample of the current study's participants, higher HCCs were correlated with greater pre-academic skills only in girls, and this bivariate association further varied as a function of family wealth (Armstrong-Carter et al., 2020). We hypothesized that the positive association between HCCs and adaptive outcomes may emerge in contexts of great adversity, where average low HCCs levels may indicate chronic HPAA hypo-responsivity and higher HCCs levels may reflect more optimal HPAA functioning (Armstrong-Carter et al., 2020). The unique relevance of HCCs for girls may be due to biological embedding of gender inequalities in how family resources are allocated or how household chores are distributed (UNICEF, 2013). Given gender inequalities in educational opportunities in rural Pakistan (Bari & Najam, 2017; Lloyd et al., 2007) and other LMIC settings (Glick & Sahn, 2000; Rammohan & Dancer, 2008; Shabaya & Konadu-Agyemang, 2004), future work should investigate whether and how biological processes relevant to learning and self-regulation vary across boys and girls (e.g., Tarullo et al., 2017) and whether these differences reflect gendered contextual experiences.

The reports of mixed findings as well as null associations of HCC with both children's behavior (Kao et al., 2018) and direct assessments of cognitive skills (Chau et al., 2017; Palmer et al., 2013) highlight the need to continue examining whether and how HCCs relate to young children's adaptation. With more empirical research representing diverse children's experiences, we will gain better understanding of the complex role that stress physiology may play in development of EFs and self-regulation. Since studies of young children in LMICs have revealed that children's height-for-age or stunting status (≤−2SD of height-for-age) is linked with daily salivary cortisol (Dobrova-Krol et al., 2008; Nyberg et al., 2012), future work needs to understand the role of stress physiology while controlling for linear growth.

1.4 | Relevance of EFs and self-regulation behaviors for preschoolers' school readiness outcomes

1.4.1 | Pre-academic skills

EFs and self-regulation behaviors capture complementary adaptive processes relevant to early learning and academic achievement (Blair & Raver, 2015). EFs can promote knowledge and skill acquisition by supporting young children's ability to manipulate mental representations and symbols, flexibly shift between various strategies, inhibit impulsive responses, disregard irrelevant information, and avoid perseverating on ineffective approaches. On the other hand, self-regulation behaviors can help children engage and persist on a learning task, ignore environmental distractions, and actively listen, collaborate, and consider alternate perspectives. Both direct assessments of EFs and adult reports of self-regulation behaviors have been separately linked to kindergarten readiness skills and academic achievement in studies of young children across the globe (Allan et al., 2014; Cortés Pascual et al., 2019; Robson et al., 2020). A large study of economically and ethnically diverse preschoolers from the United States has also shown that PSRA-AR predicts emerging literacy and numeracy skills (Daneri et al., 2018).

Empirical studies in HICs have revealed that, when studied together, direct assessments of EFs and teacher reports of self-regulation behaviors uniquely predict academic outcomes in young children (e.g., Dekker et al., 2017; Finders et al., 2021; Lonigan, Allan, et al., 2017). Two studies in Kenya and Ghana have extended these findings, showing that an adapted PSRA-AR measure explained additional variance in academic outcomes in preschool and primary school children, controlling for direct assessment of EFs (Ahmed et al., 2021; Willoughby et al., 2019). In a study of Albanian preschoolers, however, only direct EF assessment emerged as a significant predictor of early academic skills, with no additional variance explained by assessor, teacher, or parent reports of self-regulation behaviors (von Suchodoletz et al., 2015). More work is needed to understand the added value and predictive power of assessor observations of children's self-regulation for academic outcomes, over and above direct assessments of EFs.

1.4.2 | Social-emotional behaviors

In addition to supporting early learning and academic achievement, EFs and self-regulation behaviors support young children's expression of prosocial behaviors and inhibition of inappropriate or aggressive behaviors (Blair & Raver, 2015; Denham et al., 2012; Eisenberg et al., 2011). Children's abilities to focus and maintain attention, control impulsive behaviors, manage upset feelings, consider different perspectives, and plan their actions promote sustained prosocial interactions and behaviors (e.g., collaboration, conflict resolution, empathy, helping, and sharing) and minimize behavioral problems (e.g., aggression, hostility, anxiety). Direct assessments of EFs predict teacher reports of young children's social skills and behavioral problems in the United States (Denham et al., 2012; Eisenberg et al., 2001; Hughes & Ensor, 2011; Obradović, 2010; Rimm-Kaufman et al., 2009). A meta-analysis also revealed a significant association between EFs and lower externalizing behavior problems in preschoolers (Schoemaker et al., 2013). Research linking direct assessment of EFs with adult reports of young children's social-emotional behaviors in LMICs has been rare. A notable exception is a study of Turkish preschoolers that linked lower EFs with teacher reports of emotional dysregulation in the classroom (Orta et al., 2013).

Further, parent and teacher ratings of self-regulation behaviors have been linked to greater social skills, prosocial behaviors, and lower levels of behavioral problems in HIC samples of young children (Lonigan, Spiegel, et al., 2017; Valiente et al., 2011; White et al., 2013). In a small sample of Head Start preschool children from the Chicago School Readiness Project (CSRP) in the United States, assessor report via the PSRA-AR was positively correlated with teacher report of social skills and negatively related to teacher report of externalizing and internalizing behavioral problems (Smith-Donald et al., 2007). In a separate sample of Head Start preschoolers from the CSRP, McCoy and Raver (2011) found that, over and above child and family covariates, the PSRA-AR predicted teacher-reported internalizing behaviors, but not externalizing behaviors. Due to the limited availability of valid and pragmatic assessments of self-regulation behaviors and socio-emotional behaviors for young children in LMIC contexts (Finch et al., 2018; Haslam et al., 2019), there is a general lack of research linking adult observations of children's self-regulation behaviors with adult reports of different socio-emotional behaviors. Thus, it is critical to examine whether EFs and self-regulation behaviors uniquely explain variability in young children's prosocial behaviors and behavioral problems, especially in LMIC settings.

1.5 | Current study

The current study was designed to address the limitations of previous work by employing performance-based measures of EFs and assessors' ratings of self-regulation (inhibitory control and positive affect/engagement behaviors) to investigate covariation, contextual predictors, and developmental implications for age-salient outcomes of cognitive and behavioral control in preschoolers living in rural Pakistan. The experience of Pakistani children is generally representative of other disadvantaged children growing up in LMICs. Pakistan is the sixth most populous country in the world, with 21% of the population living below the international poverty line of $1.25 USD a day (United Nations Development Programme [UNDP], 2014). Exposure to infectious diseases, food insecurity, and lack of micronutrients in diet contribute to high rates of infant mortality (74 per 1000) and under-five mortality (89 per 1000; National Institute of Population Studies [NIPS] Pakistan & ICF International, 2013). The majority of Pakistan's population (64%) lives in agricultural areas, and striking health and educational disparities have been noted between children in rural and urban districts (Di Cesare et al., 2015; NIPS Pakistan & ICF International, 2013). Gender-based disparities in education, health, and opportunities in the labor market are also highly prevalent among Pakistani youth (Bari & Najam, 2017). Thus, studying children in rural Pakistan generates knowledge that is relevant to understanding and promoting early child development across the globe.

We addressed three key research questions. First, what is the association of directly assessed EFs with observed ratings of two related, yet distinct, aspects of self-regulation: inhibitory control and positive affect/engagement behaviors? Based on previous research, we hypothesized that EFs would be positively linked to both types of observed self-regulation behaviors. Second, how are contextual factors (family wealth, maternal education, number of siblings, antecedent food insecurity, and children's antecedent linear growth) related to the two types of self-regulation behaviors, as compared to previously published links with EFs (Obradović et al., 2019)? Since the birth cohort participated in the Pakistan Early Child Development Scale-Up (PEDS) Trial—a community-based, cluster-randomized control trial of early responsive stimulation and enhanced nutrition intervention from birth to age two (Yousafzai et al., 2014, 2016)—we also tested intervention effects on self-regulation behaviors. Intervention impacts on EFs have been previously reported (Obradović et al., 2019; Yousafzai et al., 2016). In addition, in a subsample of children with HCC data, we examined whether HCCs, a measure of chronic stress, were related to self-regulation behaviors, controlling for contextual factors and children's antecedent linear growth. Since previous research with this sample revealed that HCC associations with child experiences and other outcomes varied across gender (Armstrong-Carter et al., 2020), we examined these associations separately in boys and girls. Due to limited relevant studies examining how socio-demographic markers of contextual experiences relate to observer reports of self-regulation behaviors in LMIC settings, these analyses were exploratory. Third, we tested the unique associations of EFs and two types of self-regulation behaviors for children's performance on a pre-academic skills test and maternal reports of prosocial behaviors and behavioral problems. Based on limited previous research in LMICs, we hypothesized that EFs and self-regulation skills would be uniquely associated with pre-academic skills. Due to lack of relevant prior research, we made conceptually informed hypotheses that observed inhibitory control behaviors would be more relevant for maternal report of behavior problems, whereas observed positive affect/engagement behaviors would be more relevant for maternal report of prosocial behaviors.

2 | METHOD

2.1 | Sample

Study participants came from the largely agricultural Naushahero Feroze District of Sindh province, Pakistan. The sample includes 1302 children (46% girls) and primary caregivers (99% mothers) who had previously participated in the PEDS Trial, a community-based, cluster-randomized controlled trial with a 2 × 2 factorial design (Yousafzai et al., 2014). The cohort was recruited at birth from local community centers and every infant born in the study area between April 1, 2009, and March 31, 2010, was eligible for enrollment. Children were screened for signs of severe cognitive impairments during the first 2–5 months of life. Children who did not show any signs of impairment were considered eligible and participated in the PEDS Trial during their first 2 years of life (Yousafzai et al., 2014, 2016).

The PEDS Trial consisted of two intervention arms designed to promote healthy child development. The responsive stimulation intervention promoted positive and responsive parenting practices as well as play and communication stimulation activities via individualized

coaching, support, and feedback during monthly home visits and community group meetings. The enhanced nutrition intervention provided additional education in health, hygiene, and nutrition, and delivered micronutrient supplements to the children 6 months or older. An additional control group received routine health and nutrition services. Families were randomly assigned to the control condition (n = 368), the responsive stimulation intervention (n = 383), the enhanced nutrition intervention (n = 364), or both the responsive stimulation and enhanced nutrition interventions (n = 374). More details on the intervention design and its effects are reported elsewhere (see Yousafzai et al., 2014, 2016). As reported previously, the responsive stimulation intervention was found to improve preschoolers' EFs, pre-academic skills, and prosocial skills, while enhanced nutrition improved children's motor development (Yousafzai et al., 2016). Intervention effects on the children's self-regulation behaviors have not been previously examined.

2.2 | Procedures

This longitudinal study employed data collected at three-time points: at the child's birth (within 0–2 months, n = 1489), at age 2 (n = 1391, 93% of the original sample), and at age 4 (n = 1302, 87% of the original sample). There were no significant differences in baseline characteristics between who attrited and remained in the sample for the 4-year follow-up, aside from height-for-age Z-score, which was lower in the group of children who attrited (see Yousafzai et al., 2016 for details). All data were collected by a group of Community-based Child Development Assessors who were specifically trained to interact with families and administer the assessments in Sindhi, the local language. At the child's birth, the mother or head of household reported maternal educational attainment, family wealth, and family structure including number of children. When the child was 2 years old, mothers reported their family's experience of food insecurity and a study team member directly measured children's height to capture children's early nutrition and growth. At age four, children participated in a longitudinal follow-up study that consisted of a 3-h home visit and a 3-h center visit (Yousafzai et al., 2016). Most of these visits (98.6%) occurred within 2 weeks of the child's fourth birthday. At this time, the study staff collected children's hair samples to assay for HCCs and directly assessed children's preacademic skills and EFs. A multidisciplinary team of experts and local staff spent 6 months adapting all measures for administration in the Pakistani context (Yousafzai et al., 2016). Family income and children's pre-academic skills were recorded at home. Children's hair collection and EF assessments took place at a community-based assessment center. This space was free of distraction and was specially set up for child assessments close to the villages of families. All mothers gave written informed consent (or a thumb print for consent) and could decline or decide not to participate at any time. Ethics approval for this study was obtained from the ethical review committee of the Aga Khan University in Pakistan (Protocol 2265-Ped-ERC-12) and from the institutional review board at Stanford University (Protocol ID 26174; study title: Early Childhood Cognitive Stimulation and Successful Transition to Preschool in a Disadvantaged Population in Rural Pakistan).

2.3 | Measures

Descriptive statistics for all study variables are presented in Table 1.

2.3.1 | Executive functions

Because there was no existing EF battery for preschoolers in rural LMIC, we completed an extensive process of task selection, adaptation, and evaluation (see Obradović et al., 2019). Six tasks were deemed developmentally and culturally appropriate. The Fruit Stroop (Carlson, 2005), the Knock-Tap Game (Molfese et al., 2010), the Big/Little Game (Carlson, 2005), and the Go/NoGo Game (Willoughby et al., 2010) all measured children's inhibitory control, or ability to suppress a dominant response in favor of a subdominant response. The total scores reflected the percentage correct across the test trials for the Fruit Stroop, the Knock-Tap, and the Big/Little tasks (α = .50, α = .79, α = .88, respectively) and the percentage of correct "no-go" trials (α = .82) for children who demonstrated at least 76% accuracy on "go" trials for the Go/NoGo game. The Forward Word Span (Noël, 2009) measured children's working memory, or ability to hold, update, and manipulate information in the mind over short periods of time. 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. Children who could not repeat any words, or only one word, were given a score of 1 (α = .66). The Separated Dimensional Change Card Sort (Carlson, 2005) measured children's cognitive flexibility, or ability to switch flexibly 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, followed by a rule switch and six subsequent shape trials. The total score reflected the percentage of correct post-switch trials (α = .79).

Comprehension of task rules was determined by performance on practice trials. Children who did not pass task-specific comprehension criteria did not receive a valid test score. A final composite score was created by averaging valid test scores across six EF tasks (Cronbach's α = .64, M = −0.027, SD = 0.611). Given that a three-task battery provides a reliable measure of overall EFs (Willoughby et al., 2013), the final EF composite was created for children who passed comprehension criteria for three or more tasks (91% of children who completed the EF battery). For more on EF tasks, the adaptation process, passing criteria, and the final composite, see Obradović et al. (2019).

2.3.2 | Self-regulation behaviors

The original Preschool Self-Regulation Assessment – Assessor Report (Smith-Donald et al., 2007) is an assessor report designed to provide a

TABLE 1 Descriptive statistics and bivariate correlations for all study variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	EFs	–													
2	Inhibitory control	.26***	–												
3	Pos aff/eng	.28***	.35***	–											
4	Pre-academic	.22***	.08**	.21***	–										
5	Behav probs	−.07*	−.14***	−.02	−.03	–									
6	Prosocial	.12***	.05	.12***	.20***	−.19***	–								
7	RS	.13***	−.02	.03	.17***	.02	.19***	–							
8	EN	.01	.04	.14***	.09**	−.01	−.08**	−.01	–						
9	Male	−.01	−.05	−.02	−.02	.17***	−.08**	.03	−.05	–					
10	# Siblings	.03	.02	−.09**	−.05	−.08**	.041	.03	−.03	−.01	–				
11	Mat edu	.18***	.06*	.12***	.22***	.00	.11***	−.01	.09**	.02	−.18***	–			
12	Wealth	.14***	.02	.13***	.19***	−.04	.11***	.04	−.01	−.01	−.11***	.37***	–		
13	Food	−.12***	−.06*	−.10***	−.13***	.08**	−.06*	−.07*	−.14***	.04	.12***	−.22***	−.25***	–	
14	Height	.23***	.04	.19***	.17***	.01	.10***	−.04	.03	−.02	−.10***	.23***	.27***	−.17***	–
	N	1144	1274	1274	1261	1298	1298	1302	1302	1302	1302	1302	1,294	1,301	1,278
	Mean	−0.027	2.329	1.684	22.016	0.951	1.529	0.507	0.481	0.539	4.158	2.192	0.000	0.327	−2.333
	SD	0.611	0.765	0.814	14.073	0.523	0.363	0.500	0.500	0.499	2.253	3.686	1.000	0.469	1.123
	Min	1.704	0	0	0	0	0	0	0	0	1	0	−1.017	0	−6.63
	Max	1.662	3	3	84.5	2	2	1	1	1	13	16	4.664	1	1.11

Abbreviations: # siblings, number of siblings; behav probs, behavior problems; EFs, executive functions; en, enhanced nutrition intervention; mat edu, maternal education; food ins, food insecurity at age 2; height, height-for-age at age 2; pos aff/eng, positive affect/engagement; pre-academic, pre-academic skills; prosocial, prosocial skills; RS, responsive stimulation intervention.

*$p < .05$.

**$p < .01$.

***$p < .001$.

global picture of children's attention (e.g., "sustains concentration; willing to try repetitive tasks"), behavior (e.g., "remains in seat appropriately during test"), emotions (e.g., "child shows frequent positive emotions and behaviors"), and engagement (e.g., "alert and interactive, not withdrawn") as observed across the duration of an assessor-child interaction. Behaviors are rated using a four-point scale.

Eight items that capture multiple dimensions of children's self-regulation behavior while maintaining cultural sensitivity were selected for use in this study as part of a systematic process of adaptation (see the Appendix for information on adaptation and creation of the sub-scales). The first sub-scale, *inhibitory control*, captures children's ability to sustain concentration and refrain from disruptive behaviors during the assessment (four items, $\alpha = .83$). The second sub-scale, *positive affect/engagement*, captures children's alertness, enjoyment, task mastery, and active engagement with the assessor during the assessment (four items, $\alpha = .80$). On average, assessors reported high levels of inhibitory control ($M = 2.329$, $SD = 0.765$, range: 0–3, skewness = −1.252, kurtosis = 3.763), with 31% of children receiving the maximum score of 3 on the scale, suggesting possible ceiling effects. In contrast, assessors reported moderate levels of positive affect/engagement, on average ($M = 1.684$, $SD = 0.814$, range: 0–3, skewness = −0.289, kurtosis = 1.917). Positive affect/engagement scores were well-spread across the continuum of possible scores.

2.3.3 | Contextual factors

The following covariates were assessed by primary caregiver's report. *Family wealth* was assessed at baseline using maternal and head-of-household's report on 44 items reflecting ownership of property, livestock, and household assets (e.g., TV, bicycle, car), dwelling characteristics (e.g., access to water, sanitation facilities, type of flooring material), and number of bedrooms in the home (Gwatkin et al., 2000; Yousafzai et al., 2014). A binary score was assigned to individual items (0 = *absence*, 1 = *presence*). We employed a recommended principal components analysis procedure (Vyas & Kumaranayake, 2006) to weight various assets according to their salience in this population and generate a single standardized factor score representing cumulative family wealth ($M = 0$, $SD = 1$, range: −1.017 to 4.664). *Maternal education* measured the number of grades the mother completed in formal schooling at baseline ($M = 2.192$, $SD = 3.686$ range: 0–16). Parents also indicated the *number of siblings* at baseline ($M = 4.158$, $SD = 2.253$ range: 1–13); and *child's sex* (1 = *male*).

Parents reported on the frequency and extent of the family's food insecurity over the past 4 weeks (nine items; Coates et al., 2007) when the child was 2 years of age. The measure by Coates and colleagues was specifically designed to capture food insecurity across different cultural contexts, including low- and middle-income settings. To simplify interpretation, we created a binary measure of *food insecurity*, to index the availability of safe and nutritionally adequate food (1 = *food insecure*; 32.7% food insecure). In addition, trained assessors measured child's height at 24 months of age using a ShorrBoard to the nearest 0.1 cm. In accordance with standardized guidelines (Cogill, 2003), height was converted into a standardized height-for-age index using WHO Anthro software V3.2.2. HAZ values, an index of linear growth as well as chronic malnutrition or stunting (≤−2SD of height-for-age), were used in the analyses ($M = -2.333$, $SD = 1.123$, range: −6.63 to 1.11). Physical growth status at age 2 can reflect prenatal or postnatal chronic undernutrition that is especially important for healthy cognitive development (Walker et al., 2011).

2.3.4 | Pre-academic skills

We measured pre-academic skills using the Bracken School Readiness Assessment, Third Edition (BSRA-3), which comprises five subtests for color recognition, letter recognition, number and counting, sizes and comparisons, and shapes. The BSRA-3 is nonverbal and was administered as a table-top task during a home visit. Children were asked to respond to the assessor's questions by selecting a correct picture response from four or more options. Extensive work was undertaken to adapt the BSRA-3 for use in a rural Pakistani context, detailed in Appendix B. Following a review of scores, we found the distribution of subtests for color recognition, letter recognition, and numbers and counting were significantly skewed, and most children scored zero; therefore, we did not utilize these subtests. The average score on the remaining two subtests (sizes and comparisons ($\alpha = .768$) and shapes ($\alpha = .842$)) was used in analyses ($M = 22.016$, $SD = 14.073$, range: 0–84.5).

2.3.5 | Social-emotional behaviors

The parent-version of the Strengths and Difficulties Questionnaire (SDQ) was used to measure children's social-emotional behaviors (Goodman, 1997). The SDQ is a relatively short 25-item behavioral screener and has been used widely for clinical, epidemiological, and intervention research. Responses are made on a three-point Likert scale; "*not true*," "*somewhat true*," and "*certainly true*." As detailed in Appendix B, a detailed adaptation and piloting process was undertaken for the SDQ. A series of factor analyses was used to create the two subscales used in this study (see Finch et al., 2018 for details): behavior problems and prosocial skills. *Behavior problems* captured hyperactivity, temper tantrums, and fighting, whereas *prosocial skills* captured peer social skills and helpfulness. On average, parents reported moderate levels of behavior problems ($M = 0.951$, $SD = 0.523$, range: 0–3) and relatively high levels of prosocial skills ($M = 1.529$, $SD = 0.363$, range: 0–3).

2.3.6 | Hair cortisol concentrations

Hair cortisol concentrations indexed children's stress physiology. Two samples of hair (each containing multiple hair strands) were collected from the back of the head from each child. Cortisol concentrations

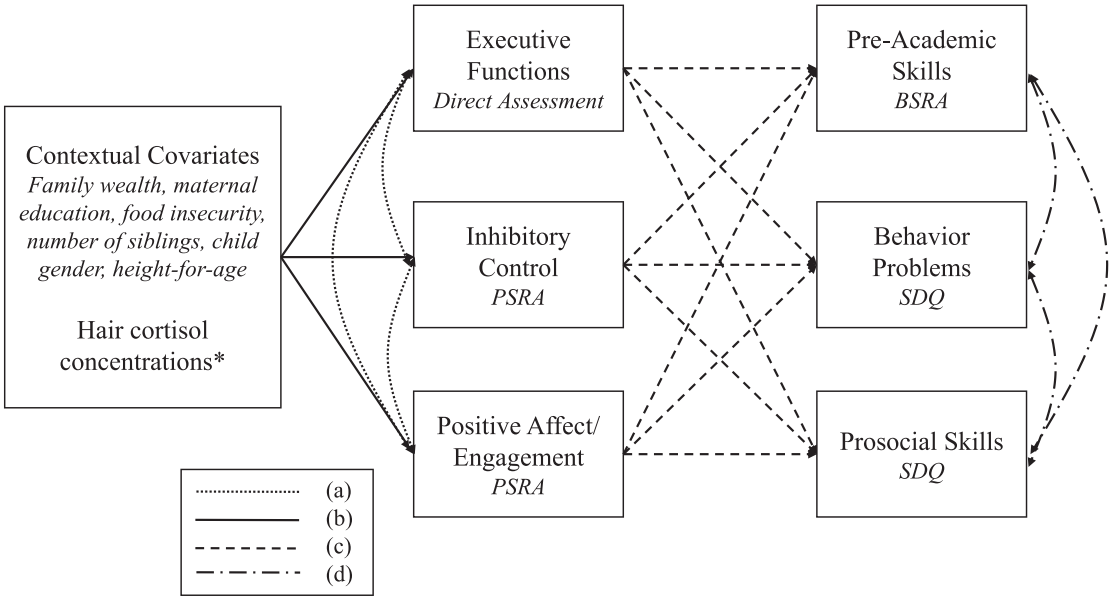

FIGURE 1 Path analytic model specified for main research questions. *Note*. PSRA = Preschool School Readiness Assessment, BSRA = Bracken School Readiness Assessment, SDQ = Strengths and Difficulties Questionnaire. Contextual covariates include responsive stimulation intervention (RS), enhanced nutrition intervention (EN), family wealth (baseline), child sex, maternal education (baseline), number of siblings (baseline), food insecurity (age 2), height-for-age (age 2). (a) Covariation among EFs and observed self-regulation behaviors (research question #1), (b) pathways from demographic and socioeconomic covariates to executive functions and observed self-regulation behaviors (research question #2), (c) pathways from EFs and observed self-regulation behaviors to pre-academic skills and social-emotional behaviors controlling for contextual covariates (research question #3), and (d) covariation among pre-academic skills and social-emotional behaviors. *Associations between hair cortisol concentrations and children's EFs and observed self-regulation behaviors were modeled in a separate analysis with a subsample. Pathways from socio-demographic covariates to pre-academic skills and social-emotional behaviors were also estimated but not shown in this model

were determined from the first 3 cm hair segment proximal to the scalp and 50 mg of hair was considered sufficient for cortisol assay. This hair segment reflects hair growth over the 3-month period prior to hair sampling, based on a hair growth rate of approximately 1 cm/month (Wennig, 2000). HCC values were log-transformed to adjust for positive skew. For details on the collection, storage, and analysis process, see Armstrong-Carter et al. (2020).

2.4 | Analytic plan

All analyses were conducted in Mplus Version 8 (Muthén & Muthén, 2021) using path analyses. We used a single model, as depicted in Figure 1, to answer the three main research questions that map on the following model pathways: (a) the covariation among EFs and two types of observed self-regulation behaviors; (b) the predictive longitudinal associations of contextual factors (family wealth, child sex, maternal education, number of siblings, food insecurity, and height-for-age) and intervention status (responsive stimulation, enhanced nutrition) with EFs and two types of observed self-regulation behaviors; (c) the predictive concurrent associations of EFs and observed self-regulation behaviors with pre-academic skills, behavior problems, and prosocial skills.

We also modeled covariation among pre-academic skills and social-emotional behaviors as well as predictive longitudinal associations of contextual factors with pre-academic skills, behavior problems, and prosocial skills. Further, we allowed for all baseline contextual factors (wealth, child sex, maternal education, and number of siblings) and intervention status (responsive stimulation, enhanced nutrition) to covary with the two variables measured at age two (food insecurity, height-for-age) to account for any intervention and baseline effects on these variables. Food insecurity and height-for-age at age two were allowed to covary with each other. Family wealth was covaried with maternal education and both were covaried with number of siblings and child sex. Missing data were accounted for using full information maximum likelihood estimation (FIML), which uses all available information in the data to create parameter estimates and standard errors (Enders & Bandalos, 2001). Because the interventions were cluster randomized at the level of the Lady Health Worker catchment, we used maximum likelihood estimation with robust standard errors and the CLUSTER command to account for the nonindependence of observations arising from the clustering of children into 80 catchments.

Separately, we conducted a multiple group analysis to examine whether HCCs were uniquely linked to children's EFs and self-regulation behaviors, controlling for other contextual covariates. We conducted these analyses separately by child sex using a multigroup model because previous work revealed that the associations of biomarkers, such as HCCs, with measures of child adaptation varies across sex (Armstrong-Carter et al., 2020; Tarullo

TABLE 2 Pathways between children's executive functions, observed self-regulation behaviors and their pre-academic and social-emotional skills

Pathway	*B*	(SE)	*p*-Value
EFs with inhibitory control	.276	.035	<.001
EFs with positive affect/engagement	.257	.031	<.001
Inhibitory control with positive affect/engagement	.354	.030	<.001
Pre-academic skills with behavior problems	−.021	.028	.457
Pre-academic skills with prosocial skills	.142	.026	<.001
Behavior problems with prosocial skills	−.183	.024	<.001
EFs → pre-academic skills	.125	.029	<.001
EFs → behavior problems	−.032	.033	.318
EFs → prosocial skills	.030	.030	.308
Inhibitory control → pre-academic skills	−.012	.028	.664
Inhibitory control → behavior problems	−.129	.032	<.001
Inhibitory control → prosocial skills	.003	.029	.913
Positive affect/engagement → pre-academic skills	.124	.033	<.001
Positive affect/engagement → behavior problems	.036	.032	.261
Positive affect/engagement → prosocial skills	.095	.028	.001

Abbreviation: EFs, executive function.

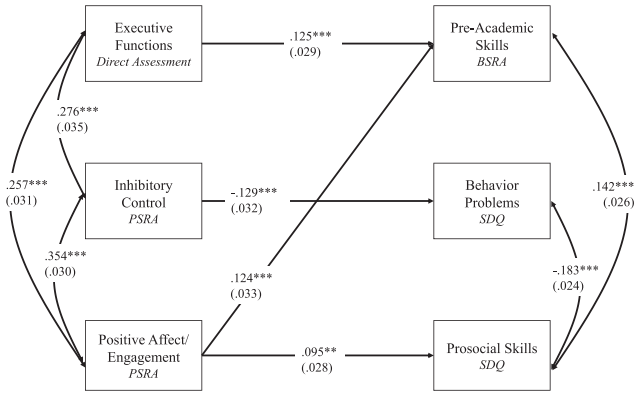

FIGURE 2 Standardized coefficients and standard errors of pathways in the between executive functions and observed self-regulation behaviors with pre-academic skills and social-emotional behaviors. *Note.* $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$. PSRA = Preschool School Readiness Assessment, BSRA = Bracken School Readiness Assessment, SDQ = Strengths and Difficulties Questionnaire. Pathways from socio-demographic covariates to executive functions, observed self-regulation behaviors, pre-academic skills, and social-emotional behaviors are not shown. Coefficients represent standardized estimates, standard errors are in parentheses. This figure shows results for research questions #1 and #3. The estimates for research question #2 can be found in Table 3.

et al., 2017). We used the same contextual covariates as specified above.

3 | RESULTS

3.1 | Associations between observed self-regulation behaviors and EFs

Bivariate correlations among all study variables are presented in Table 1 and path analytic results are presented in Table 2 with significant paths shown in Figure 2. As expected, there is significant covariation between EFs and both measures of observed self-regulated behaviors (inhibitory control: $\beta = 0.276$, $p < .001$; positive affect/engagement: $\beta = 0.257$, $p < .001$) in the path analysis. We ran two additional follow-up analyses to determine what percentage of the variance in EFs is explained by observed self-regulation behaviors, and vice versa. We found that 9.5% of the variance in EFs is explained by inhibitory control and positive affect/engagement and that 7.6% of the variance in inhibitory control and 6.2% of the variance in positive affect/engagement is explained by EFs.

3.2 | Associations of contextual factors with EFs and self-regulation behaviors

As presented in Table 3, multiple measures of contextual factors are uniquely related to children's directly-assessed EFs and observed self-regulation behaviors in path analyses. Associations between contextual factors and EFs have been reported in prior publications (Obradović et al., 2019; Obradović, Yousafzai, et al., 2016) and our findings are consistent. Bivariate correlations demonstrated that a comprehensive measure of household wealth and maternal education were positively correlated with children's EFs. However, in the path analytic model household wealth was not significantly associated with EFs ($\beta = 0.024$, $p = 0.424$), whereas maternal education remained positively linked to EFs ($\beta = 0.130$, $p < 0.001$). Number of siblings was not significantly associated with EFs in bivariate correlations, but once other variables were included in the path analysis number of siblings was also positively associated with EFs ($\beta = 0.065$, $p = 0.045$). Further, food insecurity and children's height-for-age at age two were both significantly associated with EFs in both bivariate correlations and the path analytic model (food insecurity: $\beta = -0.059$, $p = 0.023$; height-for-age: $\beta = 0.201$, $p < 0.001$).

Both bivariate correlations and the path analysis model demonstrate that a comprehensive measure of household wealth was significantly linked to children's observed positive affect/engagement ($\beta = 0.061$, $p = .042$), but not observed inhibitory control ($\beta = -0.008$,

TABLE 3 Contextual factor and covariate pathways from the path analytic model

Pathway	*B*	(SE)	*p*-Value	Pathway	*B*	(SE)	*p*-Value
RS → EFs	.129	.027	<.001	Maternal educ (b) → EFs	.130	.031	<.001
RS → inhibitory control	−.017	.035	.631	Maternal educ (b) → inhibitory control	.051	0.027	.062
RS → pos affect/engagement	.038	.034	.267	Maternal educ (b) → pos affect/engagement	.039	.027	.157
RS → pre-academic skills	.160	.028	<.001	Maternal educ (b) → pre-academic skills	.136	.031	<.001
RS → behavior problems	.026	.030	.394	Maternal educ (b) → behavior problems	.019	.028	.492
RS → prosocial skills	.179	.032	<.001	Maternal educ (b) → prosocial skills	.082	.026	.002
EN → EFs	−0.010	.029	0.721	Wealth (b) → EFs	.024	.030	.424
EN → inhibitory control	.025	.035	.487	Wealth (b) → inhibitory control	−.008	.032	.795
EN → pos affect/engagement	.127	.035	<.001	Wealth (b) → pos affect/engagement	.061	.030	.042
EN → pre-academic skills	.052	.027	.050	Wealth (b) → pre-academic skills	.073	.026	.006
EN → behavior problems	.003	.028	.904	Wealth (b) → behavior problems	−.038	.031	.218
EN → prosocial skills	−.106	.032	.001	Wealth (b) → prosocial skills	.045	.031	.144
Male child → EFs	−.014	.029	.636	Food insecurity (2) → EFs	−.059	.026	.023
Male child → inhibitory control	−.045	.027	.092	Food insecurity (2) → inhibitory control	−.046	.029	.116
Male child → pos affect/engagement	−.014	.028	.620	Food insecurity (2) → pos affect/engagement	−.020	.027	.455
Male child → pre-academic skills	−.014	.027	.596	Food insecurity (2) → pre-academic skills	−.022	.030	.451
Male child → behavior problems	.163	.023	<.001	Food insecurity (2) → behavior problems	.079	.032	.013
Male child → prosocial skills	−.082	.027	.003	Food insecurity (2) → prosocial skills	−.014	.028	.622
Num siblings (b) → EFs	.065	.032	.045	Height-for-age (2) → EFs	.201	.029	<.001
Num siblings (b) → inhibitory control	.037	.028	.176	Height-for-age (2) → inhibitory control	.023	.038	.544
Num siblings (b) → pos affect/engagement	−.052	.027	.054	Height-for-age (2) → pos affect/engagement	.154	.028	<.001
Num siblings (b) → pre-academic skills	−.006	.022	.777	Height-for-age (2) → pre-academic skills	.075	.028	.007
Num siblings (b) → behavior problems	−0.077	.031	.012	Height-for-age (2) → behavior problems	.034	.027	.203
Num siblings (b) → prosocial skills	.066	.026	.013	Height-for-age (2) → prosocial skills	.056	.029	.051

Abbreviations: (2), age 2; (b), baseline; EFs, executive functions; EN, enhanced nutrition intervention; maternal educ, maternal education; Num siblings, number of siblings; pos affect, positive affect; RS, responsive stimulation intervention.

$p = .795$). Maternal education showed positive correlations with both observed inhibitory control and positive affect/engagement in bivariate correlations but was not significantly linked to children's inhibitory control or positive affect/engagement in the path analysis ($\beta = 0.051$, $p = .062$; $\beta = 0.039$, $p = .157$; respectively). Number of siblings was not significantly associated with inhibitory control or positive affect/engagement ($\beta = 0.037$, $p = .176$; $\beta = -0.052$, $p = .054$; respectively). Food insecurity at age two was negatively correlated with both measures of observed self-regulation behaviors in bivariate correlations, but not significantly linked to these behaviors in the path

analysis model (inhibitory control: $\beta = -0.046$, $p = .116$; positive affect/engagement: $\beta = -0.020$, $p = .455$). Finally, children's height-for-age at age two was significantly linked to children's observed positive affect/engagement ($\beta = 0.154$, $p < .001$), but not to children's observed inhibitory control ($\beta = 0.023$, $p = .544$) in both bivariate correlations and the path analytic model (coefficients presented). We ran sensitivity analyses to examine the role of concurrent food insecurity at age four for children's directly-assessed EFs and observed self-regulation behaviors. In a model that included both measures of food insecurity, we found no significant effects of food insecurity at age four for EFs or observed self-regulation behaviors. However, the negative effect of food insecurity at age two for children's EFs remained.

Given that intervention impacts on children's observed self-regulation behaviors have not been published before, we also want to highlight that the responsive stimulation intervention did not have significant impacts on children's inhibitory control or positive affect/engagement at age four ($\beta = -0.017$, $p = .631$; $\beta = 0.038$, $p = .267$, respectively). However, the enhanced nutrition intervention had a positive effect on children's positive affect/engagement ($\beta = 0.127$, $p < .001$), but not their inhibitory control ($\beta = 0.025$, $p = .487$).

3.3 | Associations of stress physiology with EFs and self-regulation behaviors

A set of follow-up analyses were conducted on a subset of the sample ($n = 535$) who had valid hair cortisol data collected at age four (see Armstrong-Carter et al., 2020 for details on data collection and subsample information). In female children, HCCs were not significantly associated with EFs, but were positively associated with the two measures of observed self-regulation behaviors (inhibitory control: $\beta = 0.133$, $p = .009$; positive affect/engagement: $\beta = 0.166$, $p = .001$). In male children, HCCs were not associated with EFs or observed self-regulation behaviors.

3.4 | Path analyses predicting pre-academic skills and social-emotional behaviors

After controlling for a robust set of demographic and socioeconomic covariates, we examined the unique contributions of EFs and observed self-regulation behaviors for children's pre-academic skills and social-emotional behaviors, as shown in Table 2 and Figure 2. Both EFs and observed positive affect/engagement had unique, positive effects on children's pre-academic skills ($\beta = 0.125$, $p < .001$; $\beta = 0.124$, $p < .001$, respectively). Finally, observed inhibitory control had a unique, negative effect on children's behavior problems ($\beta = -0.129$, $p < .001$), whereas observed positive affect/engagement had a positive effect on children's prosocial skills ($\beta = 0.095$, $p = .001$). We found significant covariation between children's prosocial skills and pre-academic skills ($\beta = 0.142$, $p < .001$), but not their behavior problems and pre-academic skills ($\beta = -0.021$, $p = .457$). Finally, as expected, there was significant covariation between behavior problems and prosocial skills ($\beta = -0.183$, $p < .001$).

4 | DISCUSSION

Young children's emerging EFs—such as their abilities to suppress a pre-potent response, ignore interfering stimuli, mentally manipulate information, and flexibly shift between competing rules—relate to their early family experiences and support their early learning and relationships, in both HIC and LMIC studies (Obradović & Willoughby, 2019; Zelazo et al., 2016). The current study demonstrated the value of using both direct assessment of EFs and assessor report of self-regulation behaviors when studying early child development in a rural LMIC setting. EFs and two types of observed self-regulation behaviors were interrelated but demonstrated unique associations with early contextual experiences, stress physiology, and school readiness outcomes in preschoolers living in rural Pakistan.

4.1 | Convergence of pre-schoolers' assessed EFs with observed self-regulation behaviors

Adult assessors were trained to reliably observe and rate two distinct aspects of children's self-regulation behaviors during structured assessment protocols: (1) inhibitory control of attention and behavior and (2) displays of positive affect and engagement. These two aspects of self-regulation showed a moderate association. The positive affect and engagement composite captured more variability in children's behavior than the negatively skewed inhibitory control composite. About a third of participants displayed a ceiling level of inhibitory control behaviors. Skewed distributions are common when analyzing behavioral data in community samples of children who tend to display behaviors that largely conform with adults' expectations and social norms. Young children's compliance with adult instructions (e.g., waiting between tasks, not touching materials, sitting in a chair) are also culturally valued in rural LMIC settings like Pakistan. There is a need to develop items that capture more variability in young children's effortful control of attention and behavior in LMICs. Behavioral markers of good self-regulation in LMICs setting may reflect pursuit of collectivistic goals and fulfillment of social responsibility. A recent mixed-method study in Tanzania offered a good example of how to develop survey assessments of social and emotional skills that align with adults' cultural values and goals (Jukes et al., 2021). While this work corroborated the importance of being obedient, respectful, disciplined, attentive, and polite, the behaviors that mapped onto these constructs relied on EF and self-regulation skills. For example, successful and timely completion of chores and errands requires focused attention, impulse control, working memory, and cognitive flexibility. Future work should measure culturally and developmentally appropriate behaviors that differentiate children's strengths in application of EFs and self-regulation in home and educational settings without confounding culturally specific goals and values with cognitive

and behavioral processes supporting them. This work may necessitate development of new EF tasks that elicit observable use of skills towards achieving collective goals and engaging in communal duties.

Our findings further revealed that children's performance across six EF tasks was significantly related to assessors' ratings of both inhibitory control behaviors and positive affect and engagement. Controlling for contextual covariates (wealth, parental education, food insecurity, number of siblings, child sex and linear growth), composite performance on EF tasks explained 7.6% and 6.2% of variability in observed inhibitory control and positive affect/engagement, respectively. The two aspects of self-regulation behaviors, which shared only 12% of variance, together explained 9.5% of variance in EFs over and above the same covariates. The magnitude of these associations were modest and similar to analogous findings in young children from HICs (Obradović, Portilla, et al., 2016; Toplak et al., 2013), indicating the relative independence of the three constructs.

4.2 | Contextual experiences: Socio-economic resources, nutritional experiences, and stress

Family wealth uniquely predicted only children's observed positive affect/engagement, when controlling for other covariates. Previous studies with this sample showed that baseline family wealth indirectly related to preschoolers' EFs via more proximal enrichment experiences such as the quality of home stimulation and maternal cognitive scaffolding behaviors (Obradović, Yousafzai, et al., 2016; Obradović et al., 2019). In contrast, maternal education, a proxy for maternal cognitive skills (Obradović et al., 2019), significantly predicted only children's performance on EF tasks over and above other covariates. Future studies should investigate potential mechanisms underlying the unique link of family wealth with assessor reports of children's affect, task mastery, and social engagement. For example, children from more economically-advantaged families may feel more comfortable displaying emotions and engaging with an unknown adult assessor during a novel structured assessment because they have had more out-of-home experience than their less advantaged peers. While the structured assessment context may help standardize observer ratings, it is important to interrogate how children's temperament, culture, and privilege contribute to different subjective experiences and systematic inequities in the assessment context in ways that could influence both the child's behavior and performance on EF tasks (Obradović & Steyer, 2022). It is also possible that differences in family wealth could be perceived in the child's or parent's appearance, biasing the assessor's observation, akin to a United States study that showed teacher ratings of children's clothing were related to their observation of classroom engagement (Fitzpatrick et al., 2016). Before scaling up the use of assessor ratings of children's behaviors, it is critical that we gain better understanding of potential observer biases.

We extended our own and others' work identifying children's height-for-age at the end of their second year as a robust predictor of preschool EFs (Black et al., 2019; Obradović, Yousafzai, et al., 2016; Obradović et al., 2019), by showing that it also significantly explained variation in children's observed positive affect and engagement behaviors. Low height-for-age during the first 1000 days of the child's life, an important marker of early growth retardation and stunting, is considered a serious, longitudinal risk for cognitive development (Black et al., 2017; Grantham-McGregor et al., 2007), but it tends to show more modest associations with psychosocial outcomes (Perkins et al., 2017). Our study shows that early linear growth may have unique implications for preschoolers' regulation and expression of positive affect, task mastery, and social engagement. Future research should examine whether the increased risk of experiencing delayed cognitive skills, infection, and physical fatigue may explain the link between children's linear growth and subsequent self-regulation behaviors, or whether the association is socially mediated by children's behavioral reticence or the assessor's judgement of children's physical appearance.

In contrast, children's experience of antecedent family food insecurity was a unique predictor only of EFs. Follow-up analysis confirmed the significant role of antecedent (and not concurrent) food insecurity, highlighting the need to further study how the timing, intensity, and duration of family food insecurity uniquely impacts development across early childhood (Oliveira et al., 2020). Finally, controlling for both child physical growth and family food insecurity at 24 months of age, we found that exposure to a nutritional intervention consisting of enhanced educational messages and micronutrient supplement during the first 2 years of life had long-term benefits for preschoolers' positive affect and engagement behaviors. While cognitive control and related cognitive skills have been prioritized as outcome measures of nutritional interventions, studying behavioral and emotional control may reveal important processes by which early nutritional experiences impact school readiness and learning-relevant behaviors.

This study also advances understanding of the hypothesized role that stress hormones may have on development of self-regulation in early childhood (Blair & Raver, 2012; Obradović, 2016). We found that higher levels of HCCs were related to greater inhibitory control, positive affect, and engagement in preschooler girls. This finding is consistent with previous work with this sample showing that higher levels of HCCs might be adaptive and protective for girls via a positive link with higher levels of pre-academic skills, family wealth, and maternal education only in the female subsample (Armstrong-Carter et al., 2020). This finding also builds on our previous discovery of sex-specific neurobiological correlates of cognitive skills (Tarullo et al., 2017). A study of German preschoolers revealed that associations between HCCs and self-regulated behavior varied by children's sex, such that higher HCC was associated with lower ADHD symptoms only in boys (Pauli-Pott et al., 2017). Given that family context may further qualify the link between chronic activation of the HPA axis and development of young children's self-regulation and cognitive skills (Armstrong-Carter et al., 2020; Pauli-Pott et al., 2017), there is a need to further investigate how HCC levels may reflect young children's biological adaptations to gendered experiences at home, especially in rural LMICs settings, where girls face inequities in resource allocation, educational investments, and household chore distribution. Promotive effects of elevated

HCCs need to be studied in the context of potential chronic hyporesponsivity of the HPA axis in disadvantaged rural LMIC settings.

4.3 | Implications of EFs and self-regulation behaviors for developmental outcomes

Given global interest in assessing EFs and self-regulation behaviors in early childhood as markers of school readiness and broader adaptation (Haslam et al., 2019; Obradović & Willoughby, 2019), our results provide additional evidence that there is added value to employing both assessment approaches. Corroborating recent findings of two prior studies of primary school children's academic achievement in Africa (Ahmed et al., 2021; Willoughby et al., 2019), we showed that preschoolers' performance on EF tasks and observers' ratings of their positive affect and engagement independently predicted children's pre-academic skills, as indexed by knowledge of sizes, shapes, and comparisons of physical properties. Our findings contrast with a study of Albanian preschoolers which demonstrated that assessor ratings were a significant, but not unique correlate of early academic skills (von Suchodoletz et al., 2015). Interestingly, observations of children's inhibitory control behaviors, which conceptually align more closely with the assessed EFs, did not emerge as a unique predictor in our study, suggesting that these related aspects of observed self-regulation should be studied as distinct processes, and that combining them may result in null findings. It is possible that ratings focused on children's displays of positivity, task mastery, and engagement may capture self-regulation behaviors that promote independent early learning and evoke more positive or sustained learning-relevant interactions with adults. Further, ratings of these behaviors may reflect temperamental tendencies that are privileged in educational spaces and dyadic educational interactions. Researchers should identify pedagogical strategies that foster these interactive behaviors in culturally and developmentally appropriate ways, while also ensuring that learning opportunities and experiences are inclusive and supportive of children who are less likely to display positive affect and task mastery or socially engage with educators.

The current study also demonstrated the much-needed construct validity of the PSRA-AR ratings with maternal report of socio-emotional behaviors. Assessor ratings of positive affect and engagement uniquely predicted maternal reports of prosocial behaviors (e.g., being generous, helpful, considerate, kind, and liked), whereas assessor ratings of inhibitory control uniquely predicted maternal reports of behavioral problems (e.g., being restless, fidgety, upset, and aggressive). Assessor observations of young children's self-regulation during a structured standardized assessment procedure reflected their behaviors at home and with their caregivers. This convergent validity is especially significant in a rural LMIC context, where obtaining adult ratings of young children's contextualized behaviors can be challenging (Finch et al., 2018; McCoy et al., 2018). Despite the significant bivariate correlations, EFs did not significantly predict socio-emotional behaviors, suggesting that observations of contextualized behaviors, no matter how brief, have more predictive validity than performance-based tasks. Finally, in contrast to maternal report, assessor report of children's behaviors did not vary across sex. This divergence should be further studied in relation to assessor training, item composition, and observation context.

4.4 | Limitations

The current sample was large and representative of young Pakistani children living in rural areas. Our participants' experiences may have differed from those growing up in other LMICs, especially within urban settings. The employed battery of EF tasks primarily assessed inhibitory control skills consistent with the age and developmental capacities of our sample. Performance-based measures should be expanded, especially in older children, to include more robust measures of working memory and cognitive flexibility. Further, we employed an adapted version of the PSRA-AR using items that were deemed by cultural experts to be culturally, developmentally, and contextually relevant. Future work should focus on expanding the PSRA-AR measure to include more aspects of self-regulation behaviors. Finally, repeated measurement of EFs and self-regulation behaviors would have enabled much needed longitudinal investigation of stability and change in these processes.

5 | CONCLUSION

Assessor report of children's self-regulation, used alongside direct assessment of EFs, can help us better understand young children's adaptation to early experiences and school readiness in a rural LMIC setting. Children's exposure to the nutritional intervention and antecedent linear growth uniquely explained variability in their displays of positive affect, task mastery, and social engagement during a structured assessment protocol, underscoring the need to study how early nutritional experiences and physical growth may promote or undermine behaviors that support learning and the formation of positive relationships (Black et al., 2021). The study also demonstrated the unique relevance of both types of behaviors for school readiness, and it showed that assessor ratings can be employed when maternal report is not available, as the two approaches capture related behaviors. Despite the promise of assessor ratings in advancing the study of early developmental processes in LMICs, it is critical to further investigate sources of potential observer bias as well as the cultural relevance and variability of behavioral markers before scaling up this pragmatic assessment approach. Thus, two assessment approaches with complementary and mutually informative values should be leveraged to examine the effectiveness of early childhood care and education programs and policies (Britto et al., 2017; Richter et al., 2017).

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The findings, conclusions, and opinions here are those of the authors and do not represent views of the funding agencies. The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

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