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Early and Concurrent Home Stimulation: Unique and Indirect Links With Fine Motor Skills Among 4-Year-Old Children in Rural Pakistan

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Fine motor skills enable children to make precise and coordinated movements with their hands and support their ability to engage in everyday activities and learning experiences. In a longitudinal study of 1,058 4-year-old children in rural Pakistan (n = 488 girls), we examined how prior and concurrent levels of home stimulation relate to change in fine motor skills from ages 2 to 4 while controlling for family wealth, maternal education, number of siblings at birth, prior and concurrent measures of children's physical growth and food insecurity, and prior motor skills at age 2. Moreover, we tested whether the association between early home stimulation and subsequent fine motor skills was mediated by physical growth, food insecurity, motor skills at age 2, and concurrent home stimulation. Results revealed that home stimulation at 18 months was positively associated with change in fine motor skills from ages 2 to 4, over and above family socioeconomic resources. This association was mediated by physical growth, food insecurity and motor skills at age 2. In contrast to home stimulation at 18 months, home stimulation at age 4 was positively associated with concurrent motor skills at age 4 when controlling for all antecedent family factors, as well as prior and concurrent measures of physical growth and food insecurity, and prior motor skills at age 2. Findings suggest that the preschool period may be an important window of time when physically and cognitively stimulating experiences at home uniquely relate to variability in fine motor development.

Keywords: motor skills, early childhood, longitudinal, low-and-middle-income country

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Fine motor skills refer to the ability to make precise and coordinated hand movements. These skills support children's ability to actively participate in everyday activities, as well as to engage with formal and informal learning opportunities (e.g., holding a pencil, stacking objects). Although physical growth and family socioeconomic resources have been positively linked with motor development among young children living in low- and middle-income countries (LMICs; Cheung et al., 2001; Chowdhury et al., 2010; Cook et al., 2019; Muhoozi et al., 2016), the link between home stimulation and children's motor skills has rarely been studied (Rubio-Codina et al., 2016). The present study examines how prior and concurrent levels of home stimulation relate to developmental change in fine motor skills from ages 2 to 4 in a large, longitudinal study in rural Pakistan. We controlled for family wealth, maternal education, and number of siblings at birth to isolate home stimulation from access to socioeconomic resources. Further, we examined the robustness of the association between home stimulation and fine motor skills controlling for children's physical growth and food insecurity, which are closely related to motor development. Finally, we investigated whether the association between early home stimulation and fine motor development was mediated by early physical growth, food insecurity, and motor skills at age 2 and by concurrent home stimulation at age 4.

Household Socioeconomic Resources and Children's Motor Skills

Children's motor skills include "fine" or small coordinated muscle movements with fingers—for example manipulating and retrieving objects or holding pencils—and "gross" or large muscle movements that such as jumping, balancing or holding large objects (Cameron et al., 2016). Extensive research from high-

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income countries has shown that family resources (e.g., family wealth and parental education) are positively associated with children's fine and gross motor development (Brock et al., 2018; Dinehart & Manfra, 2013; Grissmer et al., 2010). In LMICs, where average levels of family wealth and parental education are lower, analogous positive associations have been observed in cross-sectional research (Chowdhury et al., 2010; Fernald et al., 2012; Muhoozi et al., 2016; Patel et al., 2013; Rubio-Codina et al., 2015). Many of these studies have combined measures of fine and gross motor skills in a single composite score. For example, socioeconomic status (based on monthly family income, parental education, and parental occupation) was positively related to motor skills among 5- to 12-year-old children in India and Nepal (Chowdhury et al., 2010; Patel et al., 2013). Similarly, poverty was a risk factor for low levels motor skills among 6- to 8-year-old children in Uganda (Muhoozi et al., 2016). One study of children ages 3.5 years and younger in Colombia distinguished between fine and gross motor skills and found that socioeconomic status was only associated with fine motor skills (Rubio-Codina et al., 2015). This work suggests that young children growing up in poverty are at particular risk for poor fine motor development.

Home Stimulation and Young Children's Motor Skills

In comparison to family wealth and parental education, we understand relatively little about how children's daily experiences in the home—such as opportunities for physical and cognitive stimulation—explain variability in motor development. Although home stimulation is positively correlated with family socioeconomic resources, it more specifically represents children's access to varied contextual experiences such as learning materials, enrichment opportunities, family companionship and routines, and responsive parenting behaviors (Hamadani et al., 2006; Patel et al., 2013; Yousafzai et al., 2014). In LMICs, cross-sectional studies using parental reports show that home stimulation is positively associated with young children's motor skills, while adjusting for family income (da Silva et al., 2017; Valadi & Gabbard, 2020). For example, in a sample of 4,649 four-year-old children across eight LMICs, children who had more opportunities to play, count, sing, or travel outside of the home with an adult family member displayed more advanced fine and gross motor skills compared with those who had fewer opportunities (Fink et al., 2019). Cross-sectional studies using a combination of parent and observer reports during a home visit show similar results (Hamadani et al., 2006; Patel et al., 2013; Rubio-Codina et al., 2016). For instance, home stimulation was positively associated with a composite of fine and gross motor skills among three-year-old children in Mexico (Osorio et al., 2010) and 7- to 9-year-old children in Nepal (Patel et al., 2013). More specifically, home stimulation was positively linked to fine motor skills among children ages 6 months to 3.5 years in Colombia, in a study that did not combine fine and gross motor skills (Rubio-Codina et al., 2016). Randomized controlled interventions designed to increase home stimulation during the first 2 years of life also improved children's gross and fine motor skills at age 2 in Brazil and Peru (Eickmann et al., 2003; Hartinger et al., 2017), central Asia (Engle et al., 2011; Jin et al., 2007), and—as in the present sample—in rural Pakistan (Yousafzai et al., 2014).

As children age from toddlerhood to age 4, they physically engage with their environment in more complex ways. Developmental changes in children's activities provide new opportunities to practice and further improve fine motor skills (Cameron et al., 2016). This suggests that the timing of home stimulation is important, and home stimulation during toddlerhood may relate to fine motor skills differently compared with home stimulation during preschool age. For example, a minimal, foundational set of motor skills—such as those that develop across the postnatal period—may be necessary for children to capitalize on opportunities for stimulation in their home environment (Wymbs et al., 2016). Longitudinal designs that measure home stimulation multiple times across early childhood may help to illuminate a sensitive period when home stimulation is most strongly related to variability in fine motor skills. Longitudinal research may also help to inform the design of developmentally-targeted interventions, in order to promote children's fine motor development most effectively. It is particularly important to examine if home stimulation across early childhood relates to fine motor skills at age 4, when children have increasing opportunities to engage independently with the physical world and educational activities.

Accounting for Physical Growth, Food Insecurity, and Change in Motor Skills Over Time

A body of research in LMICs has shown that children's height for age or stunting is robustly associated with their cognitive and motor maturation (Hamadani et al., 2014; Muhoozi et al., 2016; Patel et al., 2013). Longitudinal studies specify that stunting at age 2—relative to younger or older ages—is a particularly strong risk factor for poor neurocognitive development (Black et al., 2013; Hamadani et al., 2014; Sudfeld et al., 2015). This work suggests that physical growth at age 2 may be one pathway through which children's early experiences become embedded and relate to subsequent motor development. However, prior correlational studies have not been able to shed light on this potential pathway over time, because they have relied on indices of physical growth and motor skills measured at the same time point (Chowdhury et al., 2010; Patel et al., 2013; Rubio-Codina et al., 2016).

Theoretical models indicate that lack of access to food restricts children's physical growth and impedes motor development (Grantham-McGregor et al., 2007; Prado & Dewey, 2014). Experimental research has demonstrated that food and nutrient supplementation effectively improve fine and gross motor skills from infancy to preschool age (Larson & Yousafzai, 2017). However, most correlational studies investigating motor development in LMICs have not adjusted for family food insecurity (de Oliveira et al., 2020). One longitudinal study in Kenya found that the intensity of food insecurity from age 1 through 3 was related to parent-reports of gross motor skills, controlling for family wealth, maternal education, and child growth, but did not examine fine motor skills, or extend to the preschool age (Milner et al., 2018). This theoretical and empirical research suggests that it is important to account for food insecurity in research investigating preschoolers' motor skills—in addition to other household factors (e.g., family wealth, maternal education) and children's physical growth.

Longitudinal models that measure motor skills at multiple time points across development can reveal whether home stimulation is linked to change in motor development over time (e.g., from ages 2 to

4). Although not causal, this approach can help to illuminate possible directionality of effects by revealing whether home stimulation predicts concurrent or later motor skills over and above prior levels of motor skills. However, most prior research on motor skills in LMICs has been cross-sectional (da Silva et al., 2017; Fink et al., 2019; Valadi & Gabbard, 2020), or has used longitudinal data but only examined motor skills as an outcome at a single time point (Eickmann et al., 2003; Engle et al., 2011; Hartinger et al., 2017; Jin et al., 2007; Yousafzai et al., 2014; Yousafzai et al., 2016). To build on this work, longitudinal models that account for early motor skills and later motor skills at two time points can facilitate an understanding of whether early home stimulation predicts change in child motor development across early childhood.

Current Study

The goal of the present study was to understand how early and concurrent levels of home stimulation relate to preschoolers' fine motor skills at age 4, controlling for related family socioeconomic factors of family wealth, maternal education, and number of siblings. Further, we examined whether the association between home stimulation and fine motor skills persisted when accounting for children's physical growth, food insecurity, and early motor skills at age 2. Finally, we tested whether the link between early home stimulation and subsequent fine motor skills was mediated via physical growth, food insecurity, and concurrent home stimulation. These mediated pathways help to shed light on the developmental processes that may explain how home stimulation affects motor skills.

A longitudinal design enabled us to measure parent and observer reports of home stimulation when the child was both 18 months and 4 years old, accounting for continuity across early childhood. We used direct assessments of children's fine and gross motor skills at age 2 and fine motor skills at age 4, when children have increasing opportunities to physically engaging with formal or informal learning materials. This approach addressed whether home stimulation predicts change in motor skills from ages 2 to 4. In addition, children's height for age at 2 years reflected physical growth and nutrition during the first 2 years of life, a marker which has been shown to represent a longitudinal risk factor for poor motor development (Black et al., 2017; Grantham-McGregor et al., 2007). Our multimethod approach included parent reports, observer reports, and direct assessments to minimize potential shared-method bias.

We hypothesized that home stimulation at age 2 would be positively associated with fine motor skills at age 4 over and above family socioeconomic factors, but not when accounting for child-level factors (i.e., children's growth, access to nutrition, and motor skills at age 2), which would mediate this association. In contrast, we hypothesized that home stimulation at age 4 would be related to concurrent fine motor skills over and above both family- and child-level factors.

Method

Participants

Study participants came from the largely agricultural Naushero Feroze District in Sindh province, Pakistan. The sample was drawn from a larger study of 1,302 children (46% girls) and primary caregivers (99% mothers) who had previously participated in the Pakistan Early Child Development Scale-Up (PEDS) Trial, a community-based, cluster-randomized, controlled trial with a 2 × 2 factorial design. 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. The cohort was recruited at birth and participated in the PEDS trial during their first 2 years of life (Yousafzai et al., 2014; Yousafzai et al., 2016). The PEDS trial consisted of two intervention arms designed to promote healthy child development. The trial was administered by a group of community-based Lady Health Workers in Pakistan who were trained for over 15 months. One intervention arm, the responsive stimulation intervention, promoted positive and responsive parenting practices via individualized coaching, support, and feedback during monthly home visits and community group meetings. The other intervention arm, the enhanced nutrition intervention, provided additional education in health, hygiene, and nutrition, and also delivered micronutrient supplements for the children. A control group did not participate in either intervention. More details on the intervention design and its effects are reported elsewhere (see Yousafzai et al., 2014; Yousafzai et al., 2016). The current study does not evaluate the impact of the intervention; those results have already been published (see Yousafzai et al., 2014; Yousafzai et al., 2016). Rather, the current study controls for the impact of the intervention while evaluating the longitudinal link between home stimulation and motor skills, consistent with other published papers in this sample (Armstrong-Carter et al., 2020; Finch et al., 2018; Obradović et al., 2016).

The current study analytic sample was limited to 1,058 children who had motor skills data collected at 4 years (M_{age} = 4.02 years, SD = .03, range = 3.92–4.27). The motor skills assessment was conducted toward the end of the visit, and 244 of the full 1,302 study visits did not have enough time to include it. On average, children with motor skills data came from homes with relatively more resources compared with children missing motor skills data. Specifically, they had higher levels of home stimulation (both at 18 months and 4 years), family wealth, and height for age compared with children who do not have motor data ($p < .05$) and did not differ on any other study variables. In the study sample, 250 (23.63%) families were assigned to a control group that did not receive either intervention; 289 (27.31%) were assigned to the responsive stimulation intervention, 261 (24.67%) were assigned to the enhanced nutrition intervention, and 258 (24.38%) received both interventions.

On average, the participants were exposed to high levels of poverty and adversity. In the current study sample, the average monthly household income was approximately $100 USD (PKR 9,821.6; SD = PKR 14,283.7, range = PKR 0–200,000) at baseline in 2009 and 2010; when the average national household income was $169.73 USD (CEIC Data, 2020). Many families experienced food insecurity (30%) and a notable proportion of children were underweight (10%), stunted (14%), or wasted (6%) at age 2 (United Nations International Children's Emergency Fund [UNICEF], 2017). Primary school attendance in this sample was low, consistent with the region: 67% of mothers did not receive any formal education and 68% of mothers were illiterate. These demographic characteristics are largely similar to regional and national averages in Pakistan (UNICEF, 2017). The majority of families were Sindhi ethnicity (75%), with smaller proportions of Siraiki, Punjabi, and Muhajir ethnic groups. The majority spoke Sindhi and were Muslim, consistent with the majority of the population in Sindh province.

Procedure

The current study employs data collected at the baseline enrollment (birth) and at the 18-month, 2-year, and 4-year assessments. Most children were assessed within 2 weeks of the designated assessment age. The data collection team were blinded to prior intervention participation and received extensive training on interacting with families, understanding the evaluation constructs, administering measures, and handling assessment barriers. Throughout the PEDS trial (birth to 2 years), data were collected during home visits. At age 4, comprehensive child assessments were conducted during a three-hour center visit (which included direct assessment of motor skills) and a separate one-hour home visit (which included parental questionnaires and the observation of home environment). Participants' burden and fatigue were minimized by (a) alternating between child and maternal assessments, (b) scheduling performance measures at the beginning of the visit, (c) including set breaks and providing designated resting/napping spaces at the center, and (d) training assessors to identify when participants needed a refreshment, nap, playtime, or bathroom break. All questionnaires and child assessments were administered in the local language (Sindhi). 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; Title: Early Childhood Cognitive Stimulation and Successful Transition to Preschool in a Disadvantaged Population in Rural Pakistan).

Measures

Home Stimulation Quality

Home stimulation quality was measured with the Home Observation for Measurement of the Environment Inventory (HOME; Bradley et al., 2003). We used the infant/toddler version at 18 months and the early childhood version at 4 years. In this study, the original items were slightly adapted following extensive piloting (Obradović et al., 2016), such as the addition of culturally relevant examples and definitions (e.g., number of toys the child had access to did not need to include shop-bought toys; everyday items such as spoons and cups could also be used as toys), and the exclusion of an item focused on magazine subscription in the early childhood version. There were six dimensions at 18 months: (a) responsivity, (b) acceptance, (c) organization, (d) learning materials, (e) involvement, and (f) variety; and there were eight dimensions at 4 years: (a) learning materials, (b) language stimulation, (c) physical environment, (d) responsivity, (e) academic stimulation, (f) modeling, (g) variety, and (h) acceptance. Each item was scored as 0 (absent) or 1 (present), on the basis of mothers' reports of family living patterns and habits, observation of spontaneous mother-child interactions, and orderliness and enrichment potential of the physical home environment. A total HOME score was generated by summing all 45 items at 18 months (α = .82, M = 30.81, SD = 5.44) and 54 items at 48 months (α = .94, M = 32.07, SD = 6.74).

Motor Skills

At age 2, we assessed child motor development using the Bayley Scales of Infant and Toddler Development (3rd ed. [BSID-III]; Bayley, 2006) Motor Skills subscale. This direct observational tool assesses body control, large muscle coordination, the ability to manipulate hands and fingers, and dynamic movement. It includes up to 66 fine motor items and 72 gross motor items; the specific number of items depends on each child's performance. A mean motor skills composite score was calculated based on a conversion of the raw fine motor and gross motor skills scores to a single scaled composite motor skills score, which showed good interrater reliability (Bland Altman test = 95–96; $p < .001$).

At age 4, we assessed child motor development using the brief form of the Bruininks-Oseretsky test for Motor Proficiency–Version 2 (BOT-2), which is appropriate for age 48 months (Hassan, 2001; Piek et al., 2004) and has been used previously in LMICs (Fernald et al., 2009; Tedla et al., 2012; Yousafzai et al., 2016). We also adapted the measure for use in our sample through a process that included a pilot study of 23 children. Specifically, we translated the verbal instructions from English to Sindhi, and the research assessor conducted additional demonstrations for children to help them understand what was asked, for example if the child was unfamiliar with holding a pencil. For our fine motor skills composite, we averaged scores for seven items assessing fine motor skills and bilateral coordination. These items were (a) filling a star; (b) drawing a line through a path; (c) copying overlapping circles; (d) copying a diamond; (d) stringing blocks; (e) touching nose with index finger and eyes closed; and (f) pivoting thumb and index fingers. Five additional items were in the original BOT-2 measure but were excluded due to low variability in our sample; 88% to 91% children in our sample were unable to complete each of these items. The excluded items largely reflected gross motor skills. The final seven-item motor skills composite showed acceptable internal consistency (α = .60) and good interrater reliability (Bland Altman test = 80–91; $p < .001$).

Height for Age

Children's height for age (HAZ) at 2 years was an indicator of chronic malnutrition in the first 2 years of life, a critical period for neurocognitive and motor development across the life span (Black et al., 2013; Grantham-McGregor et al., 2007; Walker et al., 2011). We also measured height for age at age 4. Trained assessors measured children's height to the nearest .1 cm, in accordance with standardized guidelines (Cogill, 2003). Height was converted into a standardized HAZ index ($M = -2.33$, $SD = 1.12$), using the World Health Organization's Anthro software (Version 3.2.2; WHO, 2010).

Food Insecurity

Family food insecurity was assessed using a binary measure of whether the family had access to safe and nutritionally adequate food when the child was 2 and 4 years old (0 = food secure, 1 = food insecure; Coates et al., 2007).

Covariates

We controlled for child and family characteristics that have been shown to be closely related to family wealth and children's early cognitive development (Black et al., 2013) and have been previously used in numerous publications (e.g., Black et al., 2013; Yousafzai et al., 2014; Yousafzai et al., 2016). To assess family wealth, the mother or head-of-household reported on 44 items that indicate presence or absence of various assets, including ownership of property, livestock, and household assets (e.g., car, bike, TV), living conditions (e.g., access to water, sanitation facilities, type of flooring material), and number of bedrooms in the home. A binary score was assigned to individual items as 0 (absent) and 1 (present). Following the method of Vyas and Kumaranayake (2006), we used principal components analysis to weigh various assets according to their relative importance in this population and calculate a single standardized composite factor score that represented a comprehensive measure of family wealth.

Maternal education is linked with improved childcare practices related to health and nutrition and reduced odds of stunting which both impact cognitive development (Black et al., 2013). Mothers reported on their years of formal schooling ($M = 2.48$, $SD = 3.79$). Number of older siblings ($M = 2.55$, $SD = 2.43$) at baseline when the child was born indexed household size in the first years of the child's life.

In addition, we employed two binary variables to control for the published effects of the responsive stimulation (1 = responsive stimulation intervention exposure) and the enhanced nutrition interventions (2 = enhanced nutrition intervention exposure) on child cognitive outcomes (Obradović et al., 2016; Yousafzai et al., 2016).

Data and Analysis

In the analytic sample, the percentage of missing data was 3% or less for each study variable. All continuous variables were standardized. All continuous variables that exceeded four standard deviations were considered outliers and were truncated to four standard deviations The only variable affected by this procedure was family wealth ($n = 4$). Descriptive and correlation analysis were conducted in R Version 4.0. Regression and mediation analyses were conducted in Mplus Version 7.4 (Muthén & Muthén, 1998–2017) so that full information maximum likelihood could be used to include cases with partial missing data.

Following a precedent set by published studies of developmental processes using this birth-cohort (Armstrong-Carter et al., 2020; Finch et al., 2018; Jeong et al., 2019; Obradović et al., 2019; Obradovic et al., 2016; Tarullo et al., 2017), our analysis used the full sample, which is more representative of the study population and retains greater statistical power for our complex, longitudinal models (compared with the control group alone), and controlled for intervention conditions. We tested a series of four linear regression models to investigate direct associations of prior home stimulation (Models 1 and 2) and concurrent home stimulation (Models 3 and 4) with children's motor skills at age 4. We supplemented these analyses with tests of mediation to examine indirect associations between prior home stimulation and children's motor skills at age 4. All models included clustered standard errors to accounted for the clustering of data within the 80 community-based team members who administered the original intervention trial (Yousafzai et al., 2014).

Specifically, Model 1 examined associations of home stimulation at 18 months with motor skills at 4 years, controlling for sex, family characteristics at baseline (family wealth, maternal education, number of older siblings), and exposure to the responsive stimulation and enhanced nutrition interventions during the first 2 years of the child's life. Model 2 additionally included child height for age, food insecurity and motor skills at 2 years as covariates. As a follow-up analysis to Model 2, a mediation model tested whether the association between prior home stimulation and motor skills is explained by height for age, food insecurity and motor skills at 2 years. Model 3 examined whether concurrent measures of home stimulation uniquely predict preschoolers' motor skills, controlling for prior family and child characteristics (including home stimulation at 18 months). As a follow-up analysis to Model 3, a mediation model tested whether the link between early home stimulation at 18 months and motor skills at age 4 is explained by concurrent home stimulation at age 4. Finally, model 4 additionally included child height for age and food insecurity at 4 years as covariates.

Results

Table 1 provides descriptive statistics and bivariate correlations for study variables. On average, girls demonstrated higher levels of motor skills compared with boys ($r = -.06$, $p < .05$). Motor skills at 4 years were positively correlated with motor skills at 2 years ($r = .28$, $p < .01$), home stimulation at both 18 months ($r = .08$, $p < .01$) and 4 years ($r = .28$, $p < .01$), height for age at both 2 years ($r = .24$, $p < .001$) and 4 years ($r = .20$, $p < .001$), and baseline family wealth ($r = .25$, $p < .001$) and maternal education ($r = .32$, $p < .001$), and with exposure to the enhanced nutrition intervention ($r = -.08$, $p < .01$). Motor skills at 4 years were negatively correlated with food insecurity at both 2 years ($r = -.21$, $p < .001$) and 4 years ($r = -.15$, $p < .001$). Motor skills at 4 years were not correlated with exposure to the responsive stimulation intervention.

Home Stimulation in Toddlerhood

Table 2 displays regression results. Model 1 demonstrated that home stimulation at 18 months was positively associated with motor skills ($\beta = .09$, $SE = .04$, $p = .01$), controlling for family characteristics. Model 2 demonstrated that this association was no longer significant when accounting for height for age, food insecurity, and motor skills at 2 years ($\beta = .03$, $SE = .04$, $p = .51$).

As a follow-up, we tested whether the association between home stimulation at 18 months and motor skills was mediated by height for age, food insecurity and motor skills at 2 years. Table 3 presents standardized estimates for mediating pathways linking early home stimulation to motor skills. The association between early home stimulation and motor skills was significantly mediated by child height for age at 2 years (indirect effect: $\beta = .02$, $SE = .01$, $p < .001$), food insecurity at 2 years (indirect effect: $\beta = .02$, $SE = .01$, $p < .001$) and by motor skills at 2 years (indirect effect: $\beta = .06$, $SE = .01$, $p < .001$).

Table 1
Descriptive Statistics and Bivariate Correlations Among Study Constructs

Child and family characteristics	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Fine motor skills (4 years)	—													
2. Male	−0.06*	—												
3. Family wealth	0.25***	0.00	—											
4. Maternal education	0.32***	0.02	0.36***	—										
5. Siblings	−0.04	0.01	−0.14***	−0.16***	—									
6. RS	0.02	0.04	0.05	0.01	0.02	—								
7. EN	0.08**	−0.04	−0.03	0.08**	−0.03	−0.04	—							
8. HOME 18	0.08**	−0.04	−0.03	0.08**	−0.03	−0.04	1.00***	—						
9. Motor skills (2 years)	0.28***	0.05	0.24***	0.17***	−0.12***	0.20***	0.03	0.03	—					
10. Food insecurity (2 years)	−0.21***	0.00	−0.24***	−0.21***	0.13***	−0.07*	−0.11***	−0.11***	−0.18***	—				
11. HAZ (2 years)	0.24***	−0.01	0.25***	0.20***	−0.11***	−0.05	0.04	0.04	0.35***	−0.16***	—			
12. HOME (4 years)	0.28***	0.00	0.29***	0.34***	−0.02	0.07*	0.12***	0.12***	0.31***	−0.23***	0.22***	—		
13. Food insecurity (4 years)	−0.15***	0.01	−0.26***	−0.17***	0.18***	−0.05	0.05+	0.05+	−0.13***	0.25***	−0.17***	−0.12***	—	
14. HAZ (4 years)	0.35***	−0.01	0.68***	0.46***	−0.10**	0.02	0.11***	0.11***	0.29***	−0.34***	0.34***	0.39***	−0.34***	—
M	0.00		0.03	−0.01	2.47			1.49	0.00		0.00	0.00		0.00
SD	1.00		0.99	0.97	2.27			0.50	1.00		1.00	1.00		1.00

Note. RS = responsive stimulation intervention; EN = enhanced nutrition intervention; HOME = home stimulation; HAZ = height for age. Empty cells indicate binary variables.
+ = $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

Home Stimulation at Preschool Age

Model 3 demonstrated that home stimulation at 48 months was positively associated with motor skills ($\beta = .16$, $SE = .03$, $p = .001$), controlling for family characteristics at baseline, early home stimulation at 18 months, and food insecurity and child height for age at 2 years. Model 4 demonstrated that this association remained unchanged when accounting for concurrent child height for age and food insecurity at age 4 years ($\beta = .11$, $SE = .04$, $p = .001$). As a follow-up, we tested whether home stimulation at age 4 mediated the association between prior home stimulation and motor skills and found that it did (indirect effect: $\beta = .05$, $SE = .02$, $p = .001$). Please see the online supplemental material for additional results.[1, 2]

Discussion

The goal of this study was to understand how home stimulation across early childhood relates to developmental change in fine motor skills from ages 2 to 4 in rural Pakistan. Home stimulation during second year of life was positively associated with change in fine motor skills from ages 2 to 4 over and above family socioeconomic resources, but this association was not significant when accounting for children's physical growth, food insecurity and motor skills at age 2. In contrast, concurrent home stimulation was positively associated with change in fine motor skills from ages 2 to 4, controlling for antecedent family factors, as well as prior and concurrent measures of physical growth and food insecurity. Moreover, the effect of antecedent home stimulation on fine motor skills at age 4 was mediated by antecedent physical growth, food insecurity, and motor skills at age 2, and separately by concurrent home stimulation. Findings suggest that the preschool age may be an important window of time when physically and cognitively stimulating experiences at home uniquely relate to the positive development of fine motor skills. This period may be critical for interventions designed to improve fine motor skills.

Home Stimulation, Physical Growth, and Food Insecurity During Second Year of Life

Our study demonstrated that the quality of home stimulation that children experienced as toddlers was positively related to their developmental change in fine motor skills from toddlerhood to preschool age. This association was significant while controlling for family wealth, maternal education, and household size. This finding echoes prior research conducted with children in high income countries (Barnett et al., 2018; Peyre et al., 2011) and with low-income samples from high income countries (Barnett et al.,

[1] When we ran the same models within only the control group ($n = 250$), the association between home stimulation at age 4 and motor skills at age 4 was reduced from significant to marginal without age 4 covariates ($p = .07$) and nonsignificant with age 4 covariates ($p = .12$). For the full results, see the online supplemental material.

[2] We also tested whether the effects of responsive stimulation and enhanced nutrition interventions on motor skills at 4 years were mediated by home stimulation at 18 months, height for age at 2 years, and motor skills at 2 years (in the full sample). The only significant indirect effect was for responsive stimulation intervention via motor skills at age 2 ($\beta = 0.07$, $p < .001$), however, the responsive stimulation intervention did not have a significant total effect on motor skills at age 4 ($p = .868$). Please see the online supplemental material for the full results.

Table 2
Regression Results Associated With Children's Fine Motor Skills at Age 4

	Model 1			Model 2			Model 3			Model 4		
Child and family characteristics	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*	β	*SE*	*p*
Male	**−0.06**	**0.03**	**.02**	**−.14**	**0.05**	**.01**	**−0.14**	**0.05**	**.01**	**−0.16**	**0.05**	**.00**
Family wealth (baseline)	**0.15**	**0.04**	**.00**	**.09**	**0.03**	**.01**	**0.08**	**0.03**	**.02**	**0.07**	**0.03**	**.05**
Maternal education (baseline)	**0.24**	**0.03**	**.00**	**.22**	**0.03**	**.00**	**0.20**	**0.03**	**.00**	**0.20**	**0.03**	**.00**
Number of siblings (baseline)	0.04	0.03	.19	.03	0.01	.05	0.02	0.01	.12	0.02	0.01	.09
RS	−0.02	0.03	.47	−.06	0.06	.26	−0.04	0.06	.47	−0.05	0.06	.38
EN	0.06	0.03	.08	.08	0.06	.17	0.07	0.06	.25	0.07	0.06	.24
Home stimulation (18 months)	**0.09**	**0.04**	**.01**	.03	0.04	.51	−0.02	0.04	.69	−0.02	0.04	.65
Motor skills (2 years)				**.18**	**0.03**	**.00**	**0.16**	**0.03**	**.00**	**0.17**	**0.03**	**.00**
Food insecurity (2 years)				**−.20**	**0.06**	**.00**	**−0.18**	**0.06**	**.00**	**−0.16**	**0.06**	**.01**
HAZ (2 years)				**.09**	**0.03**	**.00**	**0.09**	**0.03**	**.00**	0.02	0.04	.55
Home stimulation (4 years)							**0.11**	**0.04**	**.00**	**0.11**	**0.04**	**.00**
Food insecurity (4 years)										−0.09	0.06	.14
HAZ (4 years)										**0.07**	**0.04**	**.04**

Note. RS = responsive stimulation intervention; EN = enhanced nutrition intervention; HAZ = height for age. Data are for the full sample (N = 1,058), controlling for motor skills at age 2. Associations that are significant at $p < .05$ are in bold.

2015). This longitudinal finding extends analogous cross-sectional findings from studies conducted in LMICs such as Mexico, Colombia, Uganda (Muhoozi et al., 2016; Osorio et al., 2010; Rubio-Codina et al., 2016), and even geographically close LMICs such as India and Nepal (Chowdhury et al., 2010; Patel et al., 2008).

However, the association between home stimulation during toddlerhood and subsequent motor skills was no longer significant when controlling for physical growth, food insecurity and motor skills at age 2. All three of these factors at age 2 emerged as significant predictors of preschoolers' motor skills at age 4. This result builds on previous cross-sectional work in LMICs by demonstrating that there is significant continuity in motor skills from ages 2 through 4. This finding also builds on previous work linking concurrent measures of physical growth to gross and fine motor skills during early and middle childhood (Chowdhury et al., 2010; Patel et al., 2013; Rubio-Codina et al., 2016) by demonstrating a positive, longitudinal association between physical growth at age 2 and fine motor skills at age 4. Physical growth at age 2 continued to uniquely predict subsequent fine motor skills, even after controlling for concurrent physical growth at age 4 in the final model. Moreover, concurrent physical growth was not related to change in fine motor skills in the final model. Together, these findings suggest that poor physical growth at age 2 may represent a unique risk factor for four-year-olds' fine motor development, consistent with prior evidence that stunting at age 2 is a marker of risk for poor neurocognitive development (Grantham-McGregor et al., 2007; Walker et al., 2011). Promoting children's physical growth specifically within the first 2 years of life may be a powerful approach for improving subsequent fine motor skills at school entry.

Extending previous research that accounted for physical growth (Chowdhury et al., 2010; Osorio et al., 2010; Patel et al., 2013; Rubio-Codina et al., 2016), our study also demonstrated that family food insecurity at age 2 significantly predicted children's change in fine motor skills from ages 2 to 4, over and above their physical growth. Food insecurity captures additional variance in children's early nutritional experience that is relevant for later motor development. Food insecurity also reflects aspects of families' socioeconomic resources or daily stressors that are not measured by family wealth and parental education. This finding builds on prior studies demonstrating that food insecurity was uniquely associated with school readiness (e.g., language comprehension, communication skills), while controlling for physical growth, in Kenya (Milner et al., 2018) and Bangladesh (Saha et al., 2010). Moreover, the study in Kenya found that the degree and chronicity of food insecurity between ages one and three was associated with parent reports of children's gross motor skills at age three, when accounting for family wealth, parental education, and children's physical growth (Milner et al., 2018). We extend this research by demonstrating a longitudinal link between family food insecurity and direct assessments of children's fine motor skills. Mirroring our results for physical growth, our study revealed that family food insecurity may be particularly relevant during second year of life. Specifically, food insecurity at age 2 significantly and uniquely predicted fine motor skills, whereas concurrent food insecurity at age 4 did not. This result underscores a need for future research to account for food insecurity—particularly at age 2—as an additional marker of home experiences that is related to variability in children's fine motor development.

Follow-up mediation analyses revealed that physical growth, nutrition access, and motor skills at age 2 were all independent pathways through which home stimulation during toddlerhood was associated with fine motor skills at preschool age. Home stimulation represents children's access to varied contextual experiences (i.e., learning and enrichment materials) that may directly stimulate optimal physical growth. At the same time, the quality of home stimulation also reflects greater socioeconomic resources—including access to food. In turn, sufficient food and growth promote fine motor skills over time by contributing to physical health, muscle strength and coordination (Cameron et al., 2016). Similarly, early home stimulation facilitates children's motor development measured 6 months later (at age 2), which in turn set the stage for subsequent motor development at school entry.

Table 3
Mediating Variables Linking Early Home Stimulation to Children's Motor Skills at Age 4

	HOME (18 months) → FI & HAZ (24 months) → Motor skills (48 months)			HOME (18 months) → HOME (48 months) → Motor skills (48 months)		
Total, indirect, and direct effects	β	*SE*	*p*	β	*SE*	*p*
Total effect	0.13	0.04	.00	0.03	0.04	.39
Indirect effects						
Via FI (2 years)	0.02	0.01	.00	—	—	—
Via HAZ (2 years)	0.02	0.01	.00	—	—	—
Via Motor (2 years)	0.06	0.01	.00	—	—	—
Via HOME (4 years)				0.05	0.02	.00
Total indirect effect	**0.10**	**0.02**	**.00**	**0.05**	**0.02**	**.00**
Direct effect	0.03	0.04	.52	−0.02	0.04	.69

Note. HOME = home stimulation; FI = food insecurity; HAZ = height for age. Associations that are significant at $p < .05$ are in bold.

Preschool Age as a Window of Opportunity to Foster Motor Skills

Home stimulation at age 4 emerged as a robust predictor of children's concurrent fine motor skills, controlling for prior home stimulation during toddlerhood, family socioeconomic factors, prior motor skills at age 2, and prior and concurrent measures of physical growth and food insecurity. This longitudinal finding illustrates that change in home stimulation between toddlerhood and preschool age is uniquely relevant for developmental change in young children's fine motor skills from ages 2 to 4. This longitudinal finding also extends previous cross-sectional evidence demonstrating that home stimulation and motor skills are positively related at different developmental periods across early and middle childhood (Chowdhury et al., 2010; Osorio et al., 2010; Patel et al., 2013; Rubio-Codina et al., 2016). Home stimulation during this period may be particularly relevant because children grow in their capacity to physically engage with contextual stimuli in more complex ways (Aboud et al., 2013) and benefit from new challenges and opportunities to practice small motor movements.

Homes with higher levels of stimulation offer opportunities for many different types of activities that can promote children's motor development. In our study context of rural Pakistan, home stimulation in part reflects children's access to everyday objects in the home (e.g., spoons, cups, paper, multiple sets of clothing). Children can practice manipulating and retrieving these items with their fingers, which facilitates development of their fine motor skills (Tomopoulos et al., 2006). For instance, a young child who has access to spoons and cups can practice feeding themselves with these utensils. Similarly, a young child who has multiple sets of clothing can practice manipulating buttons, zippers or drawstrings with their fingers as they dress or undress. In addition, home stimulation reflects children's access to simple homemade toys (e.g., clay, paper toys, marbles). A young child who has access to clay can practice molding it into different shapes or toys; a young child who has access to paper can practice picking up the paper and folding it. Marbles, shells, and seeds may be additional household objects and toys which facilitate fine motor practice and are more available in homes with higher levels of stimulation.

In addition to household objects and toys, the home stimulation measure reflects the degree to which parents encourage children's involvement in household activities (e.g., reading newspaper or reciting the Qur'an, homemade puzzles, games). While interacting with caregivers and other family members, children can engage their fingers and hands in ways that promote their fine motor development. For example, a child listening to their parent read might help to turn the pages; a child playing with a parent or grandparent might practice drawing with their fingers on the ground. In contrast, children raised in homes with lower home stimulation have more restricted access to objects and toys, and fewer opportunities to engage with physical activities that directly foster fine motor abilities (Landry et al., 2008).

Follow-up analyses revealed that concurrent home stimulation at age 4 fully mediated the association between home stimulation at age 2 and subsequent fine motor skills at age 4. This provides further evidence that stimulation after the first 2 years of life is critical for motor development of preschool-aged children. Children build on their existing motor skills in order to acquire and develop new motor skills (Wymbs et al., 2016). Consistent with this finding, a study of young children from Colombia showed that the strength of the cross-sectional association between home stimulation and fine motor skills increases with age between 6 and 42 months (Rubio-Codina et al., 2016). Although interventions designed to improve children's motor development often target infancy and toddlerhood (Perkins et al., 2017), our work suggests that stimulation interventions targeted during preschool age may be particularly effective for improving fine motor skills. For example, in the United States, a classroom-based motor skills program that involved playing games which require fine and gross motor skills improved preschoolers' fine and gross motor skills after 8 weeks (Hudson et al., 2020). In Ethiopia, a clinic-based psychomotor stimulation intervention—which consisted of 8 to 10 structured play sessions with a trained nurse—improved gross and fine motor skills among malnourished children, ages zero to six (Abessa et al., 2019). Future interventions focusing on promoting home stimulation in LMICs may benefit from explicitly targeting preschool age, and culturally relevant experiences that can support emerging fine motor skills. Fine motor skills in turn enable children to participate actively in everyday activities and formal and informal learning environments.

Gender Differences in Motor Development

In our study, girls demonstrated slightly higher levels of fine motor skills compared with boys. This finding is perhaps surprising because two other studies in India found that 5- to 12-year-old boys displayed higher levels of motor skills compared with girls (Chowdhury et al., 2010; Tedla et al., 2012). While our measure focused on fine motor skills, the two studies in India combined measures of fine and gross motor skills. Thus, it is feasible that girls have higher levels of fine motor skills in LMICs, whereas boys have higher levels of gross motor skills. Supporting this interpretation, two other studies from Mexico and Brazil found that girls demonstrated higher levels of fine motor skills, whereas boys showed higher levels of gross motor skills at age three (da Silva et al., 2017; Osorio-Valencia et al., 2018). Girls tend to be more involved in activities inside the home such as cooking and cleaning (Escueta et al., 2014), which require small finger movements, whereas boys are encouraged to play outside and participate in household building or maintenance projects, which may provide more opportunities for gross motor practice.

Limitations and Future Directions

Our primary analyses were based on the full sample, which included children and families who were assigned to a control group, a nutrition intervention, a responsive stimulation intervention, or both interventions during the first 2 years of life. Relative to the control group, this larger sample was more representative of the study population and provided greater statistical power for our complex, longitudinal models. Significant concurrent associations between home stimulation and motor skills at age 4 were found in the full sample, but these associations became nonsignificant when the analyses were restricted to the control group alone. This difference in results is most likely attributable to low statistical power when analyses were restricted to the control group, which makes up less than one quarter of the full sample. In our primary analysis, we controlled for intervention condition to account for the published significant effects of the responsive stimulation and enhanced nutrition interventions on our predictors and motor skills at age 2 (Yousafzai et al., 2014; Yousafzai et al., 2016). Despite these published intervention effects, we did not find any indirect effects of the interventions on motor skills at age 4 via height for age or home stimulation at age 2. The responsive stimulation intervention did significantly impact motor skills at age 4 via motor skills at age 2, reflecting a pathway of continuity across early childhood. These findings suggest that the intervention did not substantially alter the developmental processes linking home stimulation to positive change in motor skills from ages 2 to 4.

Future research should employ more culturally relevant measures of children's experiences in rural LMIC settings to identify other daily activities that can promote young children's motor development. The home stimulation measure employed in this study reflects a variety of learning materials and enrichment opportunities and has been broadly used across many LMIC settings (Bradley, 2015). It was also further adapted for use in this sample. Despite capturing adequate variability, the fine motor skills items heavily focused on holding a pencil (e.g., drawing a line, star, copying a diamond), which may reflect disparities in children's access to pencils or other school materials prior to school entry. A culturally adapted measure that is specific to activities that may promote fine motor skills in the context of rural Pakistan (e.g., making toys from clay or playing with marbles) could reflect greater variation in children's motor development. In addition, the majority of children in our sample were unable to complete the five gross motor skills items despite cultural adaptation, and these gross motor skills items has to be excluded from analyses.

Conclusions

Using a multimethod, multi-informant, longitudinal research design, this study sheds new light on the developmental timing and independent contributions of home stimulation from birth to age 4 for fine motor development from toddlerhood to preschool age in LMICs. Our results extend the literature showing that nutrition and physical growth during second year of life have long-lasting effects on children's development. Moreover, our findings suggest that age 4 may be an important window of time during which home stimulation is uniquely related to positive change in fine motor skills. We hope this work informs new interventions designed to increase home stimulation beyond infancy and toddlerhood and into preschool age (Abessa et al., 2019; Perkins et al., 2017). Given limited access to early educational opportunities outside the home in rural areas of LMICs (UNICEF, 2014), supporting home stimulation at a time of potential school entry is critical. Increasing access to formal and informal preschools, which provide play-based learning, may be another complimentary pathway to promote fine motor development.

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