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How consistent are associations between stunting and child development? Evidence from a meta-analysis of associations between stunting and multidimensional child development in fifteen low- and middle-income countries

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Abstract
Objective: Despite documented associations between stunting and cognitive development, few population-level studies have measured both indicators in individual children or assessed stunting's associations with other developmental domains.
Design: Meta-analysis using publicly available data from fifteen Multiple Indicator Cluster Surveys (MICS-4) to assess the association between stunting and development, controlling for maternal education, family wealth, books in the home, developmentally supportive parenting and sex of the child, stratified by country prevalence of breast-feeding ('low BF' <90 %, 'high BF' ≥ 90 %). Ten-item Early Childhood Development Index (ECDI) scores assessed physical, learning, literacy/numeracy and socio-emotional developmental domains. Children on track in three or four domains were considered 'on-track' overall.
Setting: Fifteen low- and middle-income countries.
Subjects: Publically available data from 58 513 children aged 36–59 months.
Results: Severe stunting (height-for-age *Z*-score <− 3) was negatively associated with on-track development (OR = 0·75; 95 % CI 0·67, 0·83). Any stunting (*Z*-score <− 2) was negatively associated with on-track development in countries with high BF prevalence (OR = 0·82; 95 % CI 0·75, 0·89). Severe and any stunting were negatively associated with physical development (OR = 0·77; 95 % CI 0·66, 0·89 and OR = 0·82; 95 % CI 0·74, 0·91, respectively) and literacy/numeracy development in high BF countries (OR = 0·45; 95 % CI 0·38, 0·53 and OR = 0·59, 95 % CI 0·51, 0·68, respectively), but not low BF countries (OR = 0·93; 95 % CI 0·70, 1·23 and OR = 0·95, 95 % CI 0·79, 1·12, respectively). Any stunting was negatively associated with learning (OR = 0·79; 95 % CI 0·72, 0·88). There was no clear association between stunting and socio-emotional development.
Conclusions: Stunting is associated with many but not all developmental domains across a diversity of countries and cultures. However, associations varied by country breast-feeding prevalence and developmental domain.

Keywords
Malnutrition
Stunting
Child development
Developmental delay
Global health
Multiple indicator cluster study
Meta-analysis

Chronic early undernutrition is known to cause stunting (height-for-age ≥2 SD below a *Z*-score normed for a well-nourished population of children of the same age and sex) and decades of research has documented associations between stunting and developmental delay[1–4]. Developmental insults such as undernutrition in a child's earliest years can have detrimental impacts on all developmental domains, as these years contain the most rapid changes in brain development[5,6]. Stunting is associated with concurrent and later cognitive delay or deficit[1,7,8] and poor school achievement[9–11]. A 40-year longitudinal study shows positive associations between stunting in childhood and reduced earnings as an adult[12].

Because stunting is easily measured, in contrast to developmental delay, it is often used as a stand-in for developmental delay in cross-sectional population health

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studies[13,14]. For example, the *Lancet* series on global early child development used stunting as a surrogate measure for developmental delay because of its well-studied associations with cognitive development. However, the authors acknowledged that it was unclear if it was also a good surrogate indicator for other developmental domains[13]. Few studies have documented country-level estimates of children's development in domains not related to physical growth or motor development (i.e. learning, literacy/numeracy and socio-emotional domains), and this gap contributes to what the *Lancet* calls 'the invisibility of poor development'[15]. Moreover, while stunting and developmental delay are associated and share many of the same risk factors (illness, poverty, low birth weight, maternal depression[16], lack of breast-feeding[17,18]), other risk factors for developmental delay – such as exposures to violence or toxic metals, lack of caregiver responsiveness and inadequate stimulation – will not necessarily result in stunting.

Here, we examine associations between stunting and multiple domains of development, using the most recent Multiple Indicator Cluster Surveys (MICS-4) that incorporated a new child development indicator that captures several domains. We test the hypothesis that moderate or severe stunting is associated with delay in overall development and with each of the measured developmental domains, controlling for wealth, maternal education and sex of the child. Where heterogeneity of associations was detected between countries, we tested whether associations varied by country-level breast-feeding prevalence at 6 months, because breast-feeding duration is a known protective factor and was not available for the children in our sample.

Methods

We compared Multiple Indicator Cluster Survey (MICS) round 4 data from fifteen low- and middle-income countries (Fig. 1, Table 1). MICS is a UNICEF-sponsored questionnaire developed to measure the burden of specific maternal and child health conditions in low- and middle-income countries[19]. Population-level household surveys are conducted approximately every 5 years and data sets are publicly available. The survey sample is designed to provide estimates of maternal and child health indicators at the national level and sometimes at the regional level (i.e. state, district, etc.). The sampling and data collection methods are designed to be sufficiently similar to allow valid comparisons to be made across countries and over time. MICS capture both anthropometric and early child development data, providing the opportunity to assess whether cross-sectional associations between stunting and developmental delay overall and within specific domains hold true across countries. The MICS-4 includes a specific series of questions designed to be an internationally comparable population indicator – the Early Child Development Index (ECDI)[20,21]. MICS-4 data sets were included in the current analysis if they were

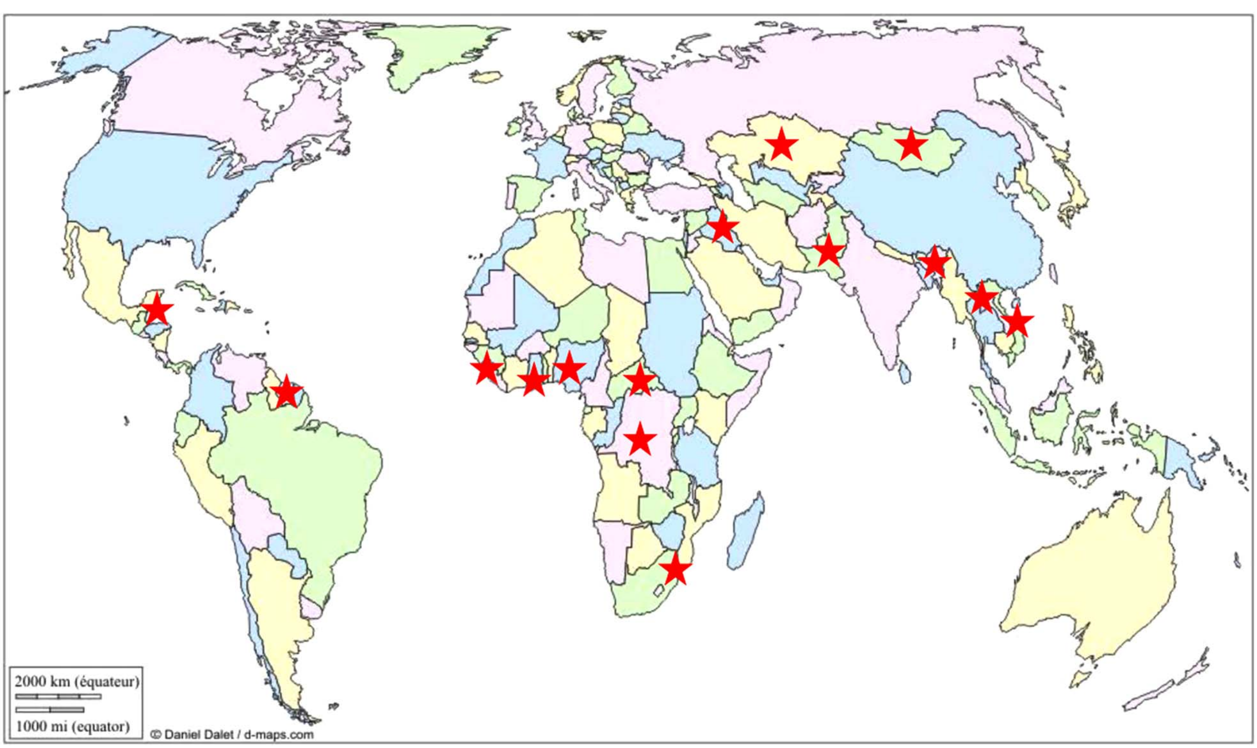

Fig. 1 Map of countries with Multiple Indicator Cluster Survey round 4 (MICS-4) data used in the analysis of stunting and development

Table 1 Population, poverty estimates, and proportions of stunting, breast-feeding and developmental risk for the fifteen countries included in the analysis

Continent and country or zone	Estimates of mid-year population (in thousands)	Year	Year of MICS	Multidimensional Poverty Index Score 2010	Rank	Proportion of children aged <5 years with moderate to severe stunting	Proportion of children breast-fed to 6 months	Proportion of children aged 3–5 years meeting developmental goals
Africa								
CAR	4487*	2011	2010	0·5123	97	49·2	96·5	45·3
DRC	67 758*	2011	2010	0·3920	94	49·7	97·2	45·6
Ghana	23 417	2009	2011	0·1397	57	23·9	98·8	67·4
Nigeria	140 004	2006	2011	0·3676	84	39·5	96·6	55·2
Sierra Leone	5890	2011	2010	0·4891	95	46·7	95·9	42·6
Swaziland	5731	2009	2010	0·1828	62	29·4	85·6	61·1
America, North								
Belize	333	2009	2011	0·0237	35	19·2	70·6	85·9
America, South								
Suriname	540	2011	2010	0·0439	41	6·3	65·8	63·4
Asia								
Bhutan	708	2011	2010	0·1190	55	34·9	98·6	68·1
Iraq	33 402	2011	2011	0·0588	45	19·4	73·5	67·3
Kazakhstan	16 339	2010	2010–2011	0·0022	7	9·5	83·9	84·6
Laos	6385	2011	2011–2012	0·2669	68	51·0	91·1	79·7
Mongolia	2781	2011	2010	0·6460	47	12·7	94·1	84·2
Pakistan (Balochistan Province)	165 150	2009	2010	0·2754	69	43	89·1	56·8
Vietnam	87 840	2011	2010–2011	0·7510	50	22·3	94·0	75·3

MICS, Multiple Indicator Cluster Survey; CAR, Central African Republic; DRC, Democratic Republic of Congo.
*Population taken from http://data.un.org/CountryProfile.

available as of December 2013, and included data on both anthropometry and specific child development indicators from 58 513 children aged 36–59 months.

Measures

Our primary outcome was 'on-track' development, determined as follows. Ten-item ECDI scores were created using the methods described in UNICEF reports[22] to assess development of children aged 36–59 months in four domains: literacy and numeracy, learning, physical, and socio-emotional. The specific questions and methods that go into the creation of the ECDI score are presented in Box 1. Briefly, caregivers were asked a series of questions regarding the child's development; a certain number of 'yes' responses is required to consider the child 'on-track' in each of the domains. This ten-item ECDI was adapted from an initial forty-eight-item version piloted in Jordan and the Philippines, after extensive testing and factor analysis, and simplified for wider use in the MICS after retesting in Kenya[23].

We then classified children into two risk categories according to UNICEF methods[22]: (i) a child who was on track in at least three of four domains was considered to be 'on-track'; and (ii) any child who was on track in fewer

Box 1 UNICEF method for constructing the Early Childhood Development Index (ECDI) in children aged 3–5 years (from http://www.childinfo.org/ecd_indicators_mics.html, accessed July 2014)

- *Literacy/numeracy:* Children are identified as being developmentally on track if they can do at least two of the following: identify/name at least ten letters of the alphabet; read at least four simple, popular words; and/or know the name and recognize the symbols of all numbers from 1 to 10.
- *Physical:* If the child can pick up a small object with two fingers, like a stick or rock from the ground, and/or the mother/caregiver does not indicate that the child is sometimes too sick to play, then the child is regarded as being developmentally on track in the physical domain.
- *Social-emotional:* The child is considered developmentally on track if two of the following are true: the child gets along well with other children; the child does not kick, bite or hit other children; and the child does not get distracted easily.
- *Learning:* If the child follows simple directions on how to do something correctly and/or when given something to do, is able to do it independently, then the child is considered to be developmentally on track in the learning domain.

than three domains was 'at risk'. A country's ECDI is calculated as the percentage of children aged 36–59 months who are 'on-track'.

Severe stunting and any stunting were defined according to WHO norms as follows: 'severe stunting' refers to height-for-age more than 3 SD below the median height-for-age of the international standard (height-for-age *Z*-score <–3) and 'any stunting' to height-for-age more than 2 SD below the international standard (height-for-age *Z*-score <–2). We hypothesized that children who fell into the 'severely stunted' category likely experienced malnutrition of longer duration or greater severity than children in the 'moderately stunted' category. We analysed these separately to determine if the strength of the associations between stunting and development would vary by severity of stunting.

We performed a meta-analysis to assess whether severe stunting or any stunting was associated with at-risk ECDI values, using applicable sampling weights and adjusting for the following *a priori* selected covariates: maternal education level[24,25], family socio-economic status[26], sex of the child, breast-fed status[27], adult support for development and number of children's books in the home. In the current data, as in previous literature, these covariates were associated with both stunting and ECDI values (see online supplementary material, Supplemental Tables 1 and 2).

'Maternal education level' was categorized as 'no education', 'primary education' or 'above primary education'. Family socio-economic status was defined using the MICS national wealth quintiles that are constructed from data on household assets, services and amenities[28]. Individual children were classified as 'ever breast-fed' or 'never breast-fed'. 'High adult support' for development was defined as in UNICEF's MICS reports, namely having an adult (over 15 years of age) do four of the following activities with the child in the last 3 d prior to the interview: sing songs, read to the child, tell stories to the child, play with the child, take the child outside or name or count things with the child.

Where meta-analysis I^2 scores indicated that the associations between stunting and development were heterogeneous among countries, we tested whether associations varied by country-level breast-feeding prevalence at 6 months, based on the rationale that the duration of breast-feeding was not available for children in our analytic sample and is associated with nutritional status and physical, cognitive and socio-emotional development[27,29]. To address this gap in our data and the consequent inability to adjust for breast-feeding duration at the individual level, we created a country-level variable of 'prevalence of breast-feeding to 6 months'. This variable was defined as the proportion of children in each country who, at the time of the survey, were aged 6–8 months and were still being breast-fed. Although these children are different individuals from the 36–59-month-olds in our study, we believe that breast-feeding practices were not likely to be significantly altered in the 2·5 years between these age cohorts. We classified countries as 'high BF' if the proportion of children between 6 and 8 months of age who were still being breast-fed was ≥90 % (roughly the sample mean) and 'low BF' otherwise. Table 1 shows the country-level prevalence of breast-feeding at 6 months for the fifteen countries in the present study. We conducted meta-analysis using the same methods as above for high BF and low BF countries separately, only in cases where pooled meta-analyses suggested heterogeneity.

Analysis

Data were analysed using the statistical software package Stata version 11·2. For each country, we estimated the univariate and adjusted odds of severe stunting and any stunting on on-track ECDI using logistic regression, and calculated odds ratios comparing stunted with non-stunted children. We then conducted meta-analyses and created forest plots of the country-specific results. If meta-analysis showed heterogeneity among all countries (I^2 value of 0·05 or lower), we conducted separate meta-analyses for countries with high (≥90 %) and low (<90 %) prevalence of breast-feeding to 6 months of age. Weights were assessed using both fixed- and random-effects models; however, differences between the two methods were less than 5 %. We present only the random-effects models below[30]. This process was then repeated for each of the four domains. Forest plots of all random-effects analyses can be found in the online supplementary material.

Results

Overall, the mean prevalence of severe stunting was 21·1 %, ranging from 1·5 % in Suriname to 26·7 % in the Democratic Republic of Congo. The mean prevalence of any stunting in children aged 36–59 months was 39·2 %, ranging from 7·5 % in Suriname to 54·1 % in Laos (Table 1). Mean prevalence of breast-feeding at 6 months was 89·1 % (Fig. 2) and mean percentage of children aged 36–59 months with on-track development was 65·5 %, ranging from 42·6 % in Sierra Leone to 85·9 % in Belize (Table 1).

Overall on-track development

Severe stunting was negatively associated with overall development (OR = 0·75; 95 % CI 0·67, 0·83) after we adjusted for maternal education, sex, wealth quintile, ever breast-fed, adult support and number of books in the house (see online supplementary material, Supplemental Fig. 1). Table 2 shows the odds ratios and 95 % confidence intervals for the relationships between severe stunting and overall on-track development, and severe stunting and domain-specific development, by country. Table 3 shows the same analyses for any stunting. In high BF countries, any stunting was negatively associated with on-track development

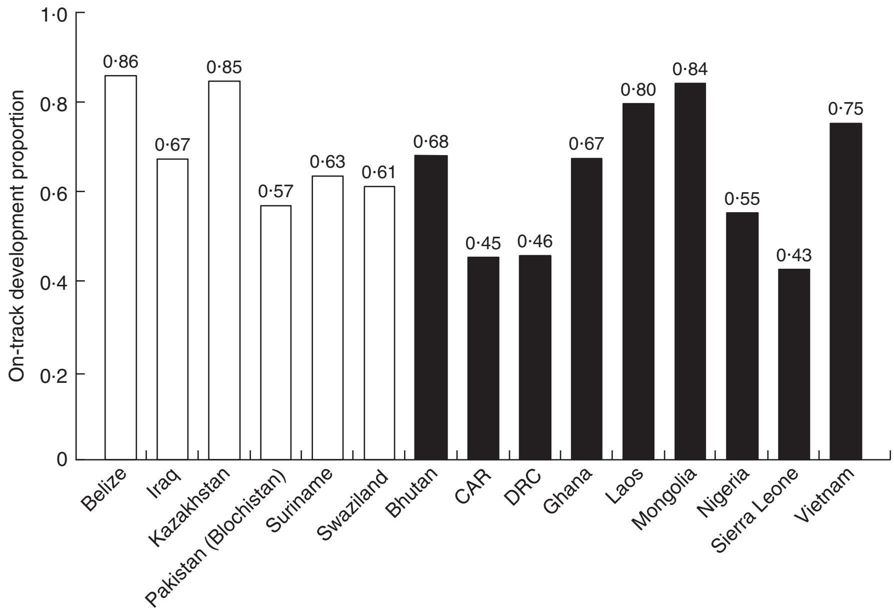

Fig. 2 Proportion of children aged 36–59 months with 'on-track' development in the Multiple Indicator Cluster Survey round 4 (MICS-4), by country (CAR, Central African Republic; DRC, Democratic Republic of Congo), stratified by country prevalence of breast-feeding to 6 months (□, 'low BF' <90 %; ■, 'high BF' ≥90 %)

(OR = 0·82; 95 % CI 0·75, 0·89). In those countries with low levels of breast-feeding, there was no consistent association between any stunting and on-track development (see online supplementary material, Supplemental Fig. 2).

Individual domains

Physical

Both severe stunting and any stunting were negatively associated with on-track development in the physical domain (OR = 0·77; 95 % CI 0·66, 0·89 and OR = 0·82; 0·74, 0·91, respectively; see online supplementary material, Supplemental Figs 3 and 4).

Literacy and numeracy

In the literacy and numeracy domain, results were highly variable for severe stunting (see online supplementary material, Supplemental Fig. 5) and any stunting (Supplemental Fig. 6) but that heterogeneity resolved after stratifying on the prevalence of breast-feeding. Among countries with high BF to 6 months, severe and any stunting were associated with lower odds of on-track development in literacy and numeracy (OR = 0·45; 95 % CI 0·38, 0·53 and OR = 0·59; 95 % CI 0·51, 0·68, respectively). In low BF countries, there was no association between severe stunting or any stunting and literacy and numeracy (OR = 0·93; 95 % CI 0·70, 1·23 and OR = 0·95; 95 % CI 0·79, 1·12, respectively).

Learning

In the learning domain, results were heterogeneous for severe stunting, even when stratifying on country breast-feeding prevalence (see online supplementary material, Supplemental Fig. 7). Any stunting was associated with on-track learning development (OR = 0·79; 95 % CI 0·72, 0·88; Supplemental Fig. 8).

Socio-emotional domain

The relationship between stunting and socio-emotional development was heterogeneous for severe and any stunting, and among all countries and after stratifying by breast-feeding prevalence (see online supplementary material, Supplemental Figs 9 and 10). No clear associations exist in these data between stunting and socio-emotional development.

Discussion

Using meta-analytic methods and MICS-4 population-level survey data from fifteen low- and middle-income countries that measured stunting and child development concurrently, we found several associations between stunting and development. Severe stunting was negatively associated with overall development, physical development and learning across all countries; and with literacy/numeracy in high BF countries after adjustment for maternal education, sex of the child, wealth quintile, adult support for development and number of books in the house. Any stunting was negatively associated with physical development and learning across all countries; and with overall development and literacy/numeracy in high BF countries. There was no clear association between stunting and socio-emotional development.

The present study contributes to a growing global literature on child health and development. To our

Table 2 Odds ratios and 95 % confidence intervals of the effect of severe stunting on on-track overall and domain-specific development, by country, stratified by country prevalence of breast-feeding to 6 months ('low BF' < 90 %, 'high BF' ≥ 90 %) as needed. Children aged 36–59 months, MICS-4

	Overall ECDI on-track		Domain on developmental index							
			Literacy/numeracy		Physical		Socio-emotional		Learning	
Country	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
Low BF										
Belize	0·54	0·23, 1·28	0·73	0·25, 2·05	1·77	0·38, 8·17	**0·49**	**0·25**, **0·94**	0·73	0·25, 2·05
Iraq	0·80	0·61, 1·06	1·26	0·87, 1·84	**0·48**	**0·33**, **0·69**	1·16	0·88, 1·54	1·02	0·76, 1·38
Kazakhstan	0·73	0·37, 1·42	1·09	0·64, 1·88	1·00	0·33, 3·10	1·17	0·45, 3·06	0·3	0·14, 0·66
Pakistan (Balochistan Province)	**0·47**	**0·36**, **0·61**	0·58	0·53, 1·05	**0·64**	**0·45**, **0·90**	**0·64**	**0·50**, **0·83**	**0·63**	**0·45**, **0·87**
Suriname*	0·74	0·28, 1·93	NA		0·70	0·10, 5·05	0·98	0·37, 2·56	0·27	0·03, 2·46
Swaziland	0·74	0·44, 1·25	0·58	0·22, 1·54	0·59	0·19, 1·82	0·94	0·56, 1·58	**0·33**	**0·16**, **0·67**
Stratum I^2†	NA		27·2 %, $P = 0·24$		NA		61·1 %, $P = 0·025$		68·7 %, $P = 0·007$	
Stratum overall	NA		0·93	0·70, 1·23	NA		NA		NA	
High BF										
Bhutan	1·11	0·77, 1·58	**0·53**	**0·34**, **0·83**	0·84	0·40, 1·77	**1·7**	**1·19**, **2·44**	**0·53**	**0·34**, **0·83**
CAR	0·87	0·70, 1·09	**0·41**	**0·22**, **0·76**	**0·63**	**0·44**, **0·89**	**1·28**	**1·01**, **1·63**	**0·63**	**0·49**, **0·81**
DRC	0·83	0·66, 1·03	**0·38**	**0·25**, **0·59**	**0·75**	**0·57**, **0·98**	1·00	0·78, 1·27	0·99	0·78, 1·26
Ghana	**0·55**	**0·37**, **0·81**	**0·49**	**0·29**, **0·83**	0·63	0·37, 1·07	0·74	0·47, 1·16	0·76	0·42, 1·38
Laos	**0·74**	**0·59**, **0·93**	**0·45**	**0·33**, **0·61**	1·01	0·64, 1·60	**0·77**	**0·59**, **0·99**	0·82	0·53, 1·27
Mongolia	0·82	0·35, 1·93	1·26	0·47, 3·35	0·59	0·08, 4·48	0·73	0·32, 1·72	0·99	0·13, 7·92
Nigeria	**0·75**	**0·63**, **0·83**	**0·36**	**0·28**, **0·47**	0·87	0·71, 1·06	0·87	0·74, 1·03	0·84	0·70, 1·01
Sierra Leone	**0·74**	**0·61**, **0·91**	**0·54**	**0·34**, **0·84**	1·08	0·84, 1·40	0·93	0·73, 1·17	0· ·9	0·68, 1·17
Vietnam	0·65	0·39, 1·07	**0·61**	**0·29**, **1·18**	0·76	0·37, 1·58	0·84	0·43, 1·67	**0·41**	**0·23**, **0·73**
Stratum I^2	NA		16·5 %, $P = 0·296$		NA		62·7 %, $P = 0·006$		49·8 %, $P = 0·043$	
Stratum overall	NA		**0·45**	**0·38**, **0·53**	NA		NA		NA	
All countries I^2	40·2 %, $P = 0·054$		NA		33·0 %, $P = 0·103$		61·9 %, $P = 0·001$		57·6 %, $P = 0·003$	
All countries	**0·75**	**0·67**, **0·83**	NA		**0·77**	**0·66**, **0·89**	NA		NA	

MICS-4, Multiple Indicator Cluster Survey round 4; ECDI, Early Childhood Development Index; CAR, Central African Republic; DRC, Democratic Republic of Congo; NA, not applicable.
Significant associations are indicated in bold font.
*Suriname literacy/numeracy odds ratio was not calculated, as severe stunting completely predicted outcome.
†If I^2 showed significant heterogeneity ($P < 0·05$), pooled odds ratios were not presented.

knowledge, it is the first study to show population-level associations between stunting and development in several domains across a wide diversity of countries and cultures. The Young Lives Project, a set of large cohort studies of the effects of poverty on children in Ethiopia, India, Peru and Vietnam, has published on the detrimental effects of stunting on cognitive development in each of these settings[7,31]; however, it has not as yet published pooled results or examined non-cognitive developmental domains. Casale and colleagues' large longitudinal 'Birth to 20' cohort study in South Africa found that early stunting was strongly associated with cognitive functioning at ages 4 and 5 years but did not predict 'social competence'[32]. Paxon and Schady's large cross-sectional study in Ecuador found that stunting was associated with poor language ability, independent of household wealth and parenting factors[33]. With evidence derived from representative samples across a larger and more diverse context, our results confirm previously-seen associations between stunting and cognition. The absence of an association between stunting and socio-emotional development in our study echoes Casale *et al.*'s finding of no association between stunting and 'social competence'.

We considered the possibility that these results would vary between countries based on breast-feeding practices. An important limitation of the study is that the MICS data do not capture duration or exclusivity of breast-feeding in children in the ages we were studying (36–59 months). However, we address this by using a country prevalence of continued breast-feeding at 6–8 months as a stratification variable. We assume that this prevalence is unlikely to have changed substantially in the two years since the birth of the children who received the ECDI.

Stratifying based on population indicators for breast-feeding allowed us to compare the relationship between stunting and ECDI score while controlling for this important covariate. Variations in the relationships between stunting and development by breast-feeding suggest that children who experience stunting in countries with high breast-feeding prevalence (perhaps children who are stunted despite being breast-fed) may be at greater risk for developmental delay than stunted children in countries with lower breast-feeding prevalence (who may not be breast-fed). Children who are stunted despite being breast-fed may have other health problems (for example, infectious diseases or metabolic issues) contributing to both stunting and delay. Mothers whose children are stunted despite being breast-fed may also have nutritional issues or other health issues that would warrant exploration. It may also be the case that children

Table 3 Odds ratios and 95 % confidence intervals of the effect of any stunting on on-track overall and domain-specific development, by country, stratified by country prevalence of breast-feeding to 6 months ('low BF' <90 %, 'high BF' ≥ 90 %) as need. Children aged 36–59 months, MICS-4

			Domain on developmental index							
	Overall ECDI on-track		Literacy/numeracy		Physical		Socio-emotional		Learning	
Country	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI	OR	95 % CI
Low BF										
Belize	0·78	0·46, 1·30	1·03	0·65, 1·63	1·19	0·48, 2·92	**0·62**	**0·42, 0·91**	0·59	0·21, 1·65
Iraq	**0·90**	**0·77, 0·96**	1·31	0·90, 1·90	**0·69**	**0·55, 0·87**	1·07	0·91, 1·27	**0·90**	**0·77, 0·96**
Kazakhstan	1·02	0·65, 1·62	0·98	0·68, 1·40	1·01	0·53, 1·93	1·13	0·65, 1·95	0·65	0·37, 1·14
Pakistan (Balochistan Province)	**0·57**	**0·45, 0·70**	0·84	0·64, 1·11	**0·68**	**0·49, 0·94**	**0·66**	**0·52, 0·82**	**0·72**	**0·53, 0·96**
Suriname	1·54	0·90, 2·59	0·68	0·30, 1·54	2·03	0·59, 6·96	1·43	0·83, 2·46	0·91	0·19, 4·26
Swaziland	0·77	0·55, 1·06	0·72	0·43, 1·20	0·71	0·36, 1·42	0·88	0·62, 1·25	0·82	0·52, 1·30
Stratum I^2*	72·7 %, *P*=0·003		10·5 %, *P*=0·35		NA		73·6 %, *P*=0·002		NA	
Stratum overall	NA		0·95	0·79, 1·12	NA		NA		NA	
High BF										
Bhutan	0·84	0·77, 1·14	**0·66**	**0·50, 0·87**	0·76	0·41, 1·42	**1·30**	**1·02, 1·65**	**0·66**	**0·50, 0·87**
CAR	**0·84**	**0·70, 0·99**	**0·52**	**0·35, 0·76**	0·73	0·54, 1·00	1·12	0·93, 1·34	**0·66**	**0·54, 0·81**
DRC	0·9	0·73, 1·09	**0·43**	**0·30, 0·62**	**0·82**	**0·65, 1·03**	0·99	0·81, 1·22	1·09	0·88, 1·36
Ghana	**0·61**	**0·47, 0·80**	**0·65**	**0·46, 0·91**	**0·64**	**0·44, 0·94**	0·70	0·52, 1·00	0·69	0·46, 1·03
Laos	0·84	0·70, 1·01	**0·70**	**0·57, 0·86**	0·99	0·70, 1·39	0·89	0·73, 1·07	0·78	0·55, 1·09
Mongolia	0·67	0·42, 1·06	0·77	0·42, 1·40	1·15	0·34, 3·90	0·60	0·36, 1·00	3·74	
Nigeria	**0·48**	**0·79, 0·91**	**0·48**	**0·40, 057**	0·87	0·73, 1·04	0·91	0·79, 1·04	**0·93**	**0·79, 1·09**
Sierra Leone	0·92	0·78, 1·11	0·71	0·51, 1·01	1·04	0·86, 1·27	0·99	0·82, 1·20	0·89	0·71, 1·11
Vietnam	0·63	0·44, 0·88	0·56	0·37, 0·85	0·57	0·35, 0·91	0·79	0·51, 1·20	0·60	0·39, 0·92
Stratum I^2	28·6 %, *P*=0·19		43·2 %, *P*=0·08		NA		55·3 %,*P*=0·22		NA	
Stratum overall	**0·82**	**0·75, 0·89**	**0·59**	**0·51, 0·68**	NA		NA		NA	
All countries I^2	NA		69·2 %, *P*=0·000		25·2 %, *P*=0·18		NA		38·9 %, *P*=0·062	
All countries	NA		**0·81**	**0·74, 0·89**	**0·82**	**0·74, 0·91**	NA		**0·79**	**0·72, 0·88**

MICS-4, Multiple Indicator Cluster Survey round 4; ECDI, Early Childhood Development Index; CAR, Central African Republic; DRC, Democratic Republic of Congo; NA, not applicable.
Significant associations are indicated in bold font.
*If I^2 showed significant heterogeneity ($P<0·05$), pooled odds ratios were not presented.

in countries with high breast-feeding prevalence who are not themselves breast-fed to 6 months are at risk for both stunting and developmental delay because of other health or social factors, such as an ill, absent or deceased mother.

We found consistent associations between severe stunting and any stunting and multidimensional development across a diversity of countries and cultures. Nevertheless, the concern raised in the *Lancet* series about using stunting as a surrogate measure for overall child development is valid. Our findings suggest that associations between stunting and development vary across domains, and we found no association between stunting and the socio-emotional domain. It is unclear whether this is because the association does not exist or whether measures of socio-emotional development must be tailored to culture and context more than measures of other developmental domains. The early child development tool used in the MICS-4 is the first to be used on such a large scale, to provide country-level assessments of development beyond stunting. This fills in a major hole in our knowledge about children's development beyond linear growth and cognition.

However, some limitations of the ECDI warrant comment. The ECDI is a parent-reported measure of development. One advantage of this is that parents can provide information based on a deep knowledge and long observation of the child, not in a laboratory or clinical setting in which a child may not act naturally. However, parents in the setting of a general interview (rather than a clinical visit, in which services would be tied to the responses) may be more apt to report overly positive results if they perceive certain answers to be socially desirable. Like most non-observation-based developmental assessments, the ECDI may not identify mild to moderate delay *v.* severe developmental delay with equal precision. For example, a 59-month-old child who cannot pick up a pencil or stick with two fingers is likely to have more severe developmental challenges than a 36-month-old child who cannot perform the same task. Additionally, generalized tools such as the ECDI are likely to be less effective at capturing domains with deep cultural variation. Despite these challenges, the use of the ECDI in the context of this large-scale country-level assessment represents a major contribution to the field and facilitates a more sophisticated approximation of early child development in these countries than was previously possible.

By applying meta-analytic methods to a large, population-based international survey that was designed to allow for cross-country and longitudinal comparisons and collected both anthropometric data and developmental data, we were able to assess whether associations between stunting and development were universal. Our findings demonstrate the value of large population-level surveys like the MICS for both cross-country comparisons and contributing to broader questions, such as the debate about universality *v.* cultural and country specificity of development and developmental indicators.

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Supplementary material

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