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# Differential influences of early growth and social factors on young children's cognitive performance in four low-and-middle-income birth cohorts (Brazil, Guatemala, Philippines, and South Africa)

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A R T I C L E I N F O

*Keywords:*
Child
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Growth
Cognition
Cohort
Low and middle income countries

A B S T R A C T

*Background:* Studies relating childhood cognitive development to poor linear growth seldom take adequate account of social conditions related to both, leading to a focus on nutrition interventions. We aimed to assess the roles of both biological and social conditions in determining early childhood cognition, mediated by birthweight and early linear growth.

*Methods:* After exploratory structural equation modelling to identify determining factors, we tested direct and indirect paths to cognitive performance through birthweight and child height-for-age at 2 years, assessed between 4 and 8.5 years of age among 2448 children in four birth cohort studies in low-and-middle-income countries (Brazil, Guatemala, Philippines and South Africa). Determinants were compared across the cohorts.

*Findings:* Three factors yielded excellent fit, comprising birth endowment (primarily maternal age and birth order), household resources (crowding, dependency) and parental capacity (parental education). We estimated their strength together with maternal height in determining cognitive performance. Percentage shares of total effects of the four determinants show a marked transition from mainly biological determinants of birth weight (birth endowment 34%) and maternal height (30%) compared to household resources (25%) and parental capacity (11%), through largely economic determinants of height at 2 years (household resources (60%) to cognitive performance being predominantly determined by parental capacity (64%) followed by household resources (29%). The largely biological factor, birth endowment (maternal age and birth order) contributed only 7% to childhood cognitive performance and maternal height was insignificant. In summary, the combined share of social total effects (household resources and parental capacity) rises from 36•2% on birth weight, to 78•2% on height for age at 24 m, and 93•4% on cognitive functioning.

*Interpretation:* Across four low- and middle-income contexts, cognition in childhood is influenced more by the parental capacity of families and their economic resources than by birth weight and early linear growth. Improving children's cognitive functioning requires multi-sectoral interventions to improve parental education and enhance their economic wellbeing, interventions that are known to improve also early childhood growth.

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## Introduction

Childhood cognition is determined by both biological and social factors, working independently and together and varying by context (Klein et al., 1972). Size at birth and childhood height are known to predict childhood cognition, as do household economic position and parental education. These determinants correlate and are influenced by inherited capacity as well as by the reproduction of familial social conditions across generations.

Young children born of low birth weight, or who are stunted or severely malnourished, have been found to perform below unaffected children on cognitive tests (Gu et al., 2017; Miller et al., 2015). The relationship between growth and cognition is weaker when child growth is less or not constrained (Pollitt et al., 1982). Similarly, children in poor socioeconomic conditions (Camargo-Figuera et al., 2014) perform below the level of their better-off peers, with the relationship similarly becoming weaker as socioeconomic conditions become less straitened. Genetics accounts for more of the variance in children's cognitive performance under favourable health and social conditions (Turkheimer et al., 2003).

In general, more attention is paid to social determinants of child cognition in research conducted in high-income countries (Paxson & Schady, 2007), where children are less exposed to threats to their health and growth. Correspondingly, there is greater emphasis on poor growth as a determinant of cognition in low- and middle-income countries. Given conditions of poor nutrition, sanitation and health care, only a few studies have attempted to flesh out social determinants of children's cognitive development (Paxson & Schady, 2007). Even fewer studies investigate growth and social factors concurrently. Most control either for the effects of child growth or for social factors, seeking to establish the main effects of the other; including in contexts in which the strength of these factors varies appreciably across as well as within populations.

Although the relationship between early child growth and cognition is not causal (Leroy & Frongillo, 2019), it is strong because they share common determinants. Nonetheless, efforts to improve child growth and reduce stunting, important as they are, are insufficient to raise cognitive performance among children in low-and middle-income countries.

In this vein, data from the five low-and-middle-income countries in the COHORTS collaboration (Brazil, Guatemala, India, Philippines and South Africa) (Richter et al., 2012), have been combined to examine the relationships between early growth and dimensions of schooling, the latter being taken as indicative of intellectual development. Martorell et al. (2020) found that larger birthweight and greater weight gain in the first two years of life were each associated with more years of schooling and decreased risk of school failure. Similarly, Adair et al. (2013) found that higher birthweight and faster linear growth in early childhood was associated with a reduced risk of not completing school. Both analyses treated social factors as controls.

The guiding assumption in these studies has been that growth is an exposure and cognition, expressed in schooling, is an outcome, rather than social factors being independent developmental determinants in their own right (Perkins et al., 2017). This assumption steers policy and programme interventions towards improving nutrition, rather than towards integrated programmes for parents and families, especially women and young children, as key to improving child cognitive development, schooling progression and economic productivity.

As a result of this bias, the relative strength of child growth and social-environment determinants of early cognition, taking both kinds of factors into account, is not clear, especially under varying socioeconomic conditions. Recent reviews differ: Sudfeld et al. (2015) find correspondence between early growth and measures of child development, whereas Prado et al. (2019) do not. Perkins et al. (2017) point out that the field remains inconclusive as a result of measurement incomparability, lack of adjustment for social conditions, and likely variations in the strength of relationships between social and biological factors from infancy through childhood and adolescence.

To examine social determinants in COHORTS analyses, Richter et al. (2018) used structural equation modelling (SEM) to explore the multi-determination of child height at two years of age. The authors show that early child growth faltering is shaped nearly as strongly by social as by biological factors, directly and indirectly. This paper aims to elucidate early biological and social determinants of childhood cognition. We do this by harmonising measures of cognitive performance across sites and applying our earlier approach to mapping multi-determination of early childhood cognitive functioning via direct and indirect pathways, in four of the five birth cohort studies in COHORTS. We apply an exploratory enhancement of SEM in Mplus (Asparouhov & Muthén, 2009). In so doing, we significantly differentiate the measured social determinants – often grouped together as socio-economic status (Bradley & Corwyn, 2002) – into parental and economic capital (Bourdieu Halseyet al, 2009). We thus attempt to tackle two of the research questions posed by Perkins et al. (2017). First, what are the components and relative strengths, in varying social contexts, of social and biological conditions that directly, or indirectly via birth weight and early physical growth, shape the cognitive development of children differentiated by sex? Secondly, how can methods such as SEM illuminate pathways through which determinants from multiple domains influence developmental outcomes?

## Methods

Each of four COHORTS sites – Cebu in the Philippines (Adair et al., 2011), Guatemala (Stein et al., 2008), Pelotas in Brazil (Victora et al., 2008) and Johannesburg-Soweto in South Africa (Richter et al., 2007) generated z-scores for cognitive measures administered to children between 4 and 8·5 years of age. In Guatemala and South Africa, standardisation was done within closely spaced age groups to accommodate maturation across the age range of children tested. In Brazil, the scores were adjusted for over-enrolment of low birth weight children. Within each site, the z-scores were converted into what we call a Cognitive Quotient (CQ) with a mean of 100 (SD 15)[23]. These harmonized CQs have reference to other children in the site sample, and not to any external norm. The Guatemala cohort was a randomised control trial. Only children in the control group were included in this analysis because the intervention resulted in improved cognition (Pollitt et al., 1993), and treatment was not applicable as a covariate in the other sites.

In Brazil, a short form of the Wechsler Preschool Intelligence Scale (WPPSI) was administered to 614 of the 5429 children enrolled in the 1993 Pelotas birth cohort, at an average age of 4 years 5 months, with a systematic over-representation of low-birth weight children (Anselmi et al., 2004). The short form of the WPPSI consisted of two verbal subtests (Comprehension and Arithmetic) and two non-verbal subtests (Figure Completion and Construction with Cubes), adapted and translated into Portuguese (Manual do Cunha, 1992).

In Guatemala (enrolment 1969–1977), a Preschool Battery was administered to 612 of the 1123 control group children aged between 4 and 7 years. It consisted of 22 tests, drawn from various sources including the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) (Engle et al., 1992).

The Philippine Nonverbal Intelligence Test (PNIT) was administered to 2252 children in Cebu (1983–1984), with an average age of 8·5 years. Modelled on the Raven's Coloured Progressive Matrices, it consists of 100 items requiring the child to indicate which target object is different from others, progressing from concrete to more abstract tasks (Guthrie et al., 1977).

In South Africa the full Raven's Coloured Progressive Matrices was administered to 827 of the 3273 children enrolled in the birth cohort in 1990, with an average age of 7·8 years. The test consists of 36 items, presented in order of difficulty. It has been shown in the Birth to Twenty Plus Study to have congruent validity with other cognitive tests (Richter et al., 2016).

The procedures in all sites were adaptations of well-established tests of cognition, the Wechsler Scales or the Raven's Matrices. Each measure was translated where necessary and adapted to the local population. The published analyses from each site, mentioned above, give confidence in their psychometric integrity and their validity as measures of child cognition.

Relevant exposures, measured similarly in each of the four sites, include child sex, birthweight (g) and height at age 2 years (cms); maternal height (cms) and age at the child's birth (y). Also included are variables measured between birth and child age of two years: maternal and paternal schooling (years completed); child birth order and dependency (ratio of children to adults); crowding (people per room); and wealth quintiles derived, following Filmer and Pritchett (1999), from site-specific lists of household assets. Analyses were disaggregated by sex and by site within sex, because boys and girls have been observed to differ in their developmental trajectories of cognitive performance by domain (Von Stumm & Plomin, 2015).

The data from Brazil (n = 614), the Philippines (n = 2252) and South Africa (n = 827) were each scaled down to match the smallest sample with available CQ data. This was done to facilitate comparisons by site and sex of coefficients, and because comparisons of nested models through adjusted chi-squared testing are sensitive to sample size. All children with cognitive scores were retained, and missing values on predictor variables were addressed by default by the structural equation modelling (SEM) package, Mplus 7.4, through Full Information Maximum Likelihood (FMIL) imputation. Covariance coverage was 0•850 in the pooled sample, against an Mplus-specified minimum of 0•100.

SEM is particularly suited to the present research problem because it offers the simultaneous testing of multiple hypothesised associations among several exogenous, intervening, and outcome variables and/or latent constructs. In classical SEM, the first stage is a "measurement model", in which the loadings of indicators on their respective latent constructs are established, as in a factor analysis. This additionally takes measurement error into account. In the second stage the "structural model", effectively a hypothesised set of regressions among the constructs and/or variables, is tested against the data, and may be adjusted. A model in which there are only observable variables, or the latent constructs are represented by their factor scores, is a "path model".

Different aspects of the fit of the model to the data are typically reflected by several indexes: the root mean square error of approximation, (RMSEA), and the standardized root mean square residual (SRMR) that adjusts for parsimony; and the comparative fit index (CFI) and its parsimony-adjusted variant, the Tucker-Lewis index (TLI). A "saturated model" including all possible paths, has RMSEA and SRMR = 0, and CFI and TLI = 1. A well-fitting model has RMSEA and SRMR<0.05, and CFI and TLI >0.95.

This paper applies a newer variant of the technique that is specific to the Mplus package (Muthén & Muthén, 2012), exploratory modelling (ESEM) (Asparouhov & Muthén, 2009), in which the loadings of all indicators on each exogenous construct, and the optimal number of such constructs, are established as part of testing the structural model. This enhances the appropriateness of factor definitions, and the prospective overall fit of likely models. Comparisons among models with differing numbers of constructs are made with the Bayesian information criterion (BIC), in which reduced BIC is sought. The total effect of each exogenous variable on the outcome, via all the paths in the final model, can be calculated. Finally, the model may be tested for whether its paths are invariant or not across subsets of data, such as sex or site or both, using groups analysis in Mplus. The respective paths are constrained to be equal and observing whether fit improves significantly as constraints are released in turn, using a corrected chi-squared difference test (Satorra & Bentler, 2010).

The analysis was accordingly conducted in four stages. First, all exposures were grouped into factors using ESEM. Two- and three-factor models were compared. There were too few exposures to consider a four-factor option. For comparability, the model specified all possible linear paths from the factors and maternal height to mediators (birth weight and height at 2 years) and the outcome (cognitive ability). Maternal height was retained as a separate predictor because of its role as a marker of intergenerational deprivation. Fig. 1 illustrates the resulting model for the three-factor option. The factors are indicated by ellipses, and the observed variables by rectangles.

To assist in identifying the relevant similarities and differences, Table 3 simplifies the content of Supplementary Table 2. The standardised path coefficients are shown only if they are significant at p ≤ 0•05, and coefficients of strength ≥0•15 are in bold. Rows in italics within each panel indicate differences significant at p ≤ 0•05 among the respective coefficients (including coefficients not shown). CIs are omitted. Coefficients are reported separately for males and females where the difference is significant.

Secondly, the factor scores were retained. With maternal height, these scores comprised the exogenous variables in a path analysis. We used the pooled sample and controls for sex and site. We examined the significance and relative strengths of these variables, both as direct predictors of cognitive functioning and via the successive mediators, birth weight and height-for-age at 24 months. Thirdly, we examined differences by sex, and by sites within sex. Finally, we applied the path analysis to establish the total effects of the exogenous variables on birth weight, height for age 24 m, and Cognitive Quotient. The effects quantified the exogenous variables' differing strengths on the successive mediators and the outcome.

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## Results

Table 1 presents means and confidence intervals (CIs) of the variables by site and sex, pooled for equally scaled samples of 612 per site. The values for the unscaled sample sizes are shown in Supplementary Table 1.

As reported in all prior published COHORTS papers (Martorell et al., 2010), there is variation within and between the cohorts on both physical and social measures. The Guatemalan and Filipino children are shorter than same-aged peers in Brazil and South Africa. The child dependency ratio is highest in Guatemala and crowding is lowest in Brazil. Maternal height, maternal schooling and paternal schooling are lowest in Guatemala and highest in South Africa. However, differences between the sites are not all in the same direction. While South African women in the sample are taller and have more schooling than Guatemalan and Filipino women, they live in considerably more crowded households.

The fit of the three-factor ESEM configuration plus maternal height was excellent (RMSEA 0•043, p(RMSEA ≤ 0•05) 0•984, CFI 0•952, TLI 0•981, SRMR 0•021, BIC 169,074), and decisively better than a two-factor configuration (RMSEA 0•056, p(RMSEA ≤ 0•05) 0•029, CFI 0•958, TLI 0•915, SRMR 0•032, BIC 169,314) according to three criteria. The probability that RMSEA ≤ 0•05 for the two-factor model was small: p = 0•029. The reduction in SRMR gained by a third factor was much greater than the conventional 0.001 test (Asparouhov & Muthén, 2009). Lastly, the Bayesian Information criterion (BIC) for the three-factor model was lower than that for the two-factor by a very large margin (Raftery, 1995).

All three factors were clearly defined by at least one strongly loading variable (Table 2). Alongside a factor we called birth endowment (defined mainly by birth order and maternal age), the model notably differentiated a household resources factor (crowding and wealth) from a parental capacity factor (parents' schooling).

The standardised coefficients and confidence intervals for the Cognitive Quotient, height-for-age z score at 24 months and birthweight by predictors are shown in Supplementary Table 2: pooled, controlling for site and sex; by sex, controlling for site; and by site within sex. The

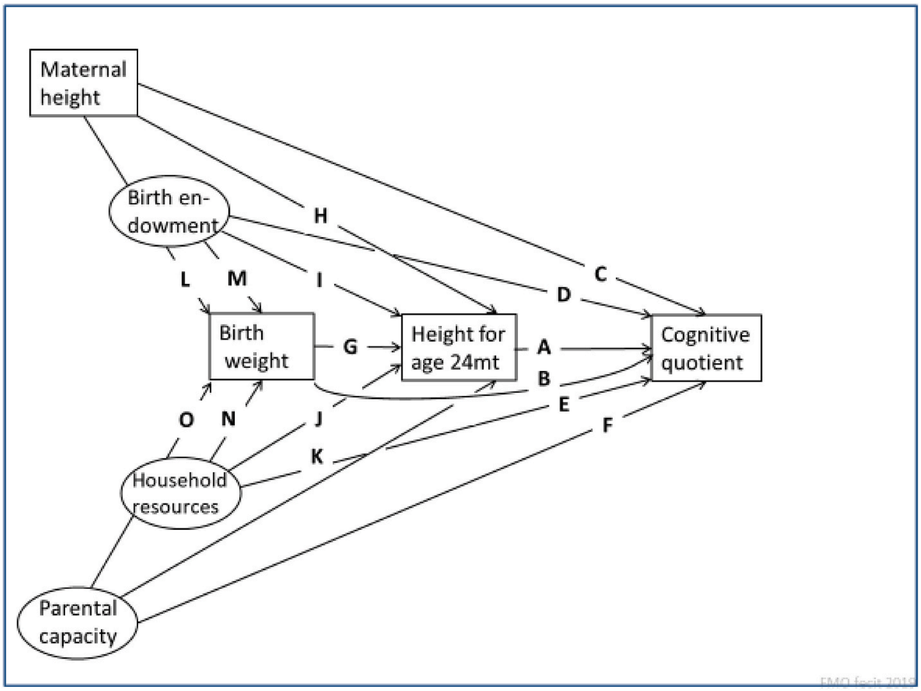


**Fig. 1.** Model depicting direct and indirect paths from maternal height and the three identified factors (birth endowment, household resources and parental capacity) to birth weight, height at 2 years, and Cognitive Quotient.

correlations among the three factors and maternal eight are shown in Supplementary Table 3. The model depicting direct and indirect paths from maternal height and the three identified factors (birth endowment, household resources and parental capacity) to birth weight, height at 2 years, and Cognitive Quotient is shown in Fig. 1.

To assist in identifying the relevant similarities and differences, Table 3 simplifies the content of Supplementary Table 2. The standardised path coefficients are shown only if they are significant at $p \leq 0 \cdot 05$, and coefficients of strength $\geq 0 \cdot 15$ are in bold. Rows in italics within each panel indicate differences significant at $p \leq 0 \cdot 05$ among the respective coefficients (including coefficients not shown). CIs are omitted. Coefficients are reported separately for males and females where the difference is significant.

The top panel of Table 3 shows that, in the pathways to *Cognitive Quotient,* the coefficient for parental capacity is much the strongest (row F: 0•45), in all sites among males and with significant differences by site among females. The path from the household resources factor is appreciably less strong (row E: 0v17), but also applies in all sites except Guatemala among males and females, again with significant by site differences among the latter. The paths from height-for-age 24 m (row A: 0•08) and birth weight (row B: 0•05) are weak, and only significant in Guatemala. The path from maternal height to Cognitive Quotient is not significant for males or females in any site.

Moving to the middle of the table, much the strongest pathway to *height-for-age 24m* is from household resources (row J: 0•37), for all sites among both males and females, and with significant differences by site. The next pathway, about half as strong, is from birth weight (row G: 0•21 M, 0•18 F), for all sites except Guatemala for males and females. The pathway from maternal height is weaker (row H: 0•011), being significant only for males in Brazil and Philippines, and females in Guatemala and Philippines. The pathway from parental capacity (row K: 0•11) is significant because of significant coefficients in Philippines among males and females, and in Guatemala among females.

Thirdly, at the bottom of Table 3, the strongest path *to birthweight* is from the birth endowment factor (row M: 0•19), across all sites among males and females. The next strongest is from maternal height (row L: 0•17 M, 0•17 F); but the path is significant only for Philippines and South Africa. The pathway from the household resources factor (row N: 0•20) is significant only for males, strongly in Brazil and weakly in South Africa.

In summary, noting only the paths in the pooled sample with coefficients $\geq 0 \cdot 15$ ($p < 0 \cdot 001$), on the left side of Table 3, the strong determinants of *birth weight* are largely biological and of roughly equal strength: birth endowment (primarily birth order) and maternal height. The strong determinants of *height-for-age at 24m* are a mix of social and biological factors, with household resources (primarily absence of crowding), stronger than birth weight. The two strong determinants of *Cognitive Quotient* are both social, with parental capacity (parents' education) more than twice as strong as household resources. All the coefficient values for the pooled sample are shown on the path diagram in Supplementary Fig. 1.

The relative shift towards social determinants among the four exogenous variables, as one moves from birth weight through height-for-age 24 m to cognitive development in childhood, may be quantified by means of total effects, as shown in Supplementary Table 4. In the pooled sample, when the four exogenous variables are expressed as percentage shares of their composite effect on *Cognitive Quotient*, social effects are much the strongest: parental capacity, 64•0% and household resources, 29•4%, compared to birth endowment, 6•6%. Maternal height is not significant, and not included in the percentages. *On height at 24m*, social effects are again stronger than biological, but less overwhelmingly: household resources dominate at this stage (60•4%) plus parental capacity (17•8%). Among the largely biological factors maternal height is evident (21•8%), while birth endowment is not. On *birth weight,* largely biological factors predominate: birth endowment (34•0%) and maternal height (29•8%). Social effects still account for more than a third: household resources (24.9%) and parental capacity (11•3%). In summary, the combined share of social total effects rises from 36•2% on birth weight, to 78•2% on height for age at 24 m, and 93•4% on cognitive functioning.

## Discussion

Our findings across four low- and middle-income country contexts

**Table 1**
Means and 95% CIs of the variables by site and sex, and pooled, for equally scaled samples of 612 per site.

| | All sites (n = 2448) | Brazil (n = 612) | | Guatemala (n = 612) | |
|---|---|---|---|---|---|
| | Male and female | Male (n = 301, 49•2%) | Female (n = 311, 50•8%) | Male (n = 312, 51•0%) | Female (n = 300, 49•0%) |
| Height for age 24 m (z-score) | 1835 (-1•75) (-1•83 to -1•67) | 299 (-0•29) (-0•45 to -0•13) | 311 (-0•19) (-0•31 to -0•06) | 192 (-3•39) (-3•56 to -3•22) | 153 (-3•41) (-3•6 to -3•23) |
| Birth weight (z-score) | 1990 (-0•5) (-0•55 to -0•46) | 298 (-0•16) (-0•29 to -0•02) | 306 (-0•31) (-0•45 to -0•17) | 96 (-0•86) (-1•09 to -0•64) | 75 (-0•63) (-0•85 to -0•41) |
| Birth order | 2447 (2•51) (2•47 to 2•56) | 301 (2•33) (2•2 to 2•46) | 311 (2•19) (2•07 to 2•31) | 311 (3•01) (2•88 to 3•15) | 300 (2•92) (2•78 to 3•06) |
| Child dependency ratio | 2334 (1•52) (1•48 to 1•57) | 296 (1•36) (1•23 to 1•49) | 310 (1•15) (1•06 to 1•24) | 270 (2•57) (2•39 to 2•76) | 245 (2•59) (2•4 to 2•78) |
| Crowding (people per room) | 2322 (2•98) (2•9 to 3•07) | 296 (1•28) (1•17 to 1•4) | 310 (1•21) (1•1 to 1•32) | 290 (4•17) (3•91 to 4•43) | 269 (4•17) (3•88 to 4•45) |
| Maternal age (at birth of child years) | 2431 (26•54) (26•29 to 26•8) | 301 (27•12) (26•37 to 27•87) | 311 (26•73) (26•04 to 27•42) | 302 (27•45) (26•67 to 28•23) | 293 (26•72) (25•94 to 27•51) |
| Maternal height (cm) | 2136 (154•32) (154–154•64) | 301 (159•9) (159•12 to 160•69) | 310 (159•55) (158•79 to 160•32) | 231 (148•47) (147•83 to 149•12) | 229 (148•3) (147•58 to 149•02) |
| Maternal schooling (years) | 2355 (6•38) (6•21 to 6•55) | 300 (7) (6•57 to 7•43) | 310 (6•94) (6•55 to 7•34) | 287 (1•55) (1•33 to 1•77) | 277 (1•54) (1•34 to 1•74) |
| Paternal schooling (years) | 2124 (6•52) (6•34 to 6•7) | 290 (6•75) (6•33 to 7•18) | 294 (6•86) (6•45 to 7•26) | 274 (2•16) (1•88 to 2•43) | 261 (2) (1•74 to 2•26) |
| Wealth (quintiles) | 2349 (3) (2•94 to 3•05) | 297 (2•97) (2•81 to 3•13) | 306 (3•01) (2•85 to 3•16) | 291 (3•03) (2•87 to 3•2) | 272 (3•08) (2•9 to 3•27) |
| Cognitive Quotient (z-score) | 2448 (100•15) (99•55 to 100•75) | 301 (98•8) (97•12 to 100•49) | 311 (101•16) (99•48 to 102•84) | 312 (102•48) (100•77 to 104•19) | 300 (100•44) (98•57 to 102•3) |
| | | **Philippines (n = 612)** | | **South Africa (n = 612)** | |
| | | **Male (n = 323, 52•8%)** | **Female (n = 289, 47•2%)** | **Male (n = 297, 48•5%)** | **Female (n = 315, 51•5%)** |
| Height for age 24 m (z-score) | | 307 (-2•57) (-2•7 to -2•45) | 273 (-2•5) (-2•63 to -2•37) | 150 (-1•48) (-1•67 to -1•29) | 151 (-1•31) (-1•49 to -1•14) |
| Birth weight (z-score) | | 318 (-0•71) (-0•82 to -0•61) | 285 (-0•61) (-0•72 to -0•49) | 297 (-0•46) (-0•58 to -0•34) | 315 (-0•63) (-0•76 to -0•5) |
| Birth order | | 323 (2•71) (2•59 to 2•84) | 289 (2•66) (2•53 to 2•8) | 297 (2•17) (2•05 to 2•3) | 315 (2•11) (1•99 to 2•23) |
| Child dependency ratio | | 322 (1•52) (1•42 to 1•62) | 289 (1•5) (1•38 to 1•61) | 290 (0•95) (0•87 to 1•03) | 312 (0•86) (0•8 to 0•92) |
| Crowding (people per room) | | 323 (3•04) (2•86 to 3•23) | 289 (3•08) (2•88 to 3•29) | 265 (3•59) (3•39 to 3•79) | 280 (3•64) (3•43 to 3•86) |
| Maternal age (at birth of child years) | | 323 (26•34) (25•68 to 27•01) | 289 (26•19) (25•5 to 26•89) | 297 (25•92) (25•19 to 26•65) | 315 (25•88) (25•18 to 26•58) |
| Maternal height (cm) | | 323 (150•72) (150•17 to 151•26) | 289 (150•48) (149•9 to 151•06) | 216 (158•16) (157•34 to 158•97) | 238 (158•02) (157•24 to 158•8) |
| Maternal schooling (years) | | 323 (7•11) (6•74 to 7•48) | 289 (7•01) (6•64 to 7•39) | 277 (9•76) (9•45 to 10•07) | 292 (9•86) (9•56 to 10•16) |
| Paternal schooling (years) | | 306 (7•31) (6•9 to 7•71) | 273 (7•11) (6•72 to 7•51) | 210 (10•84) (10•52 to 11•15) | 216 (10•7) (10•34 to 11•05) |
| Wealth (quintiles) | | 323 (2•96) (2•81 to 3•11) | 289 (2•95) (2•79 to 3•11) | 275 (3•03) (2•88 to 3•17) | 296 (2•95) (2•81 to 3•09) |
| Cognitive Quotient (z-score) | | 323 (99•34) (97•66 to 101•01) | 289 (100•74) (99•04 to 102•44) | 297 (99•96) (98•23 to 101•7) | 315 (98•33) (96•88 to 99•78) |

Data are n (Mean) (95% CIs) for each site, differentiated by sex of index child. Sites are scaled down to match the smallest site Guatemala: n = 612 analysis cases that included Cognitive Quotient.

**Table 2**
Factor loadings and definitions from the 3-factor ESEM.

| | Parental capacity | | Household resources | | Birth endowment | |
|---|---|---|---|---|---|---|
| | Estimate | p | Estimate | p | Estimate | p |
| Maternal schooling | **0•919** | <0•001 | 0•007 | 0•016 | 0•021 | 0•079 |
| Paternal schooling | **0•857** | <0•001 | -0•059 | 0•018 | -0•011 | 0•072 |
| Wealth quintile | 0•143 | <0•001 | **0•260** | <0•001 | 0•039 | 0•037 |
| Birth order | -0•177 | <0•001 | 0•001 | 0•080 | **0•947** | <0•001 |
| Child dependency ratio[a] | **0•361** | <0•001 | 0•185 | <0•001 | -0•388 | <0•001 |
| Crowding[a] | -0•012 | 0•002 | **0•757** | <0•001 | -0•012 | 0•004 |
| Maternal age | 0•013 | <0•001 | 0•192 | <0•001 | **0•704** | <0•001 |

[a] Data are factor loadings, p. Values of child dependency ratio and crowding have been reversed to run from low to high. Fit is excellent: RMSEA 0•043, CFI 0•982, TLI 0•951.

**Table 3**
Summary of significant coefficients for birth weight, height-for-age at 2 years and Cognitive Quotient, pooled by sex and by site and sex.

| | | Path | All sites, male & female | All sites, male | All sites, female | Male | | | | Female | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Brazil | Guatemala | Philippines | South Africa | Brazil | Guatemala | Philippines | South Africa |
| Cognitive Quotient on: | Height for age 24 m | **A** | 0·08 | 0·10 | | | **0·28** | | | *-0·13* | ***0·22*** | ***0·15*** | |
| | Birth weight | **B** | 0·05 | | 0·06 | | -0·24 | | | | | | 0·19 |
| | Maternal height | **C** | | | | | | | | | | | |
| | Birth endowment | **D** | | 0·05 | | | **0·29** | | | | | | |
| | Household resources | **E** | **0·17** | **0·16** | **0·19** | **0·29** | | 0·14 | 0·13 | ***0·28*** | | ***0·15*** | ***0·23*** |
| | Parental Capacity | **F** | **0·45** | **0·46** | **0·45** | **0·33** | **0·26** | **0·36** | **0·22** | ***0·35*** | ***0·24*** | ***0·32*** | ***0·18*** |
| Height for age 24 m on: | Birth weight | **G** | **0·19** | ***0·21*** | ***0·18*** | **0·32** | **0·31** | **0·19** | **0·28** | **0·31** | | **0·24** | **0·16** |
| | Maternal height | **H** | 0·11 | 0·13 | 0·09 | *0·18* | | *0·19* | | | 0·15 | 0·15 | |
| | Birth endowment | **I** | | | -0·04 | *0·09* | | *-0·05* | | | | | |
| | Household resources | **J** | **0·37** | **0·39** | **0·35** | ***0·53*** | ***0·39*** | ***0·39*** | ***0·30*** | ***0·50*** | ***0·26*** | ***0·37*** | ***0·47*** |
| | Parental Capacity | **K** | 0·11 | 0·10 | 0·10 | | | 0·18 | | | 0·15 | 0·17 | |
| Birth weight on: | Maternal height | **L** | **0·17** | ***0·17*** | ***0·17*** | | | **0·15** | **0·21** | | | ***0·16*** | ***0·21*** |
| | Birth endowment | **M** | **0·19** | **0·21** | **0·18** | **0·21** | **0·41** | **0·20** | **0·16** | **0·16** | **0·30** | **0·20** | **0·16** |
| | Household resources | **N** | 0·14 | ***0·20*** | | ***0·32*** | | | *0·15* | | | | |
| | Parental Capacity | **O** | 0·06 | *0·09* | | | | | | | | | |

All data are standardized path coefficients, significant at $p \leq 0{\cdot}05$. Coefficients in bold are stronger, $\geq 0{\cdot}15$. Rows in italics display differences significant at $p \leq 0{\cdot}05$ among the respective coefficients in the row, some of which may not be shown because insignificant.

show that cognition in childhood is influenced more by the parental capacity of families and their economic resources than by birth weight and linear growth in the first two years. The consistency of the findings in varying contexts supports the generalizability of the results.

This means that efforts to improve early cognitive functioning cannot be achieved only by nutrition interventions directed at reducing stunting (Prado et al., 2019). Rather, multi-sectoral interventions that improve parents' education and enhance their economic capacity are critical to improving human capital over the longer term. It is also the case that, as confirmed by experiences in Brazil, these multi-sectoral interventions can reduce stunting dramatically, although but their impact on cognition remains unmeasured (Martorell et al., 2010). Children who demonstrate good cognitive capacity in their early years of schooling, pre-school and foundation phase, can build on this foundation for improved learning and school progression in the subsequent years (Grantham-McGregor et al., 2007).

This analysis drew on comparable data on 2648 children from longitudinal birth cohort studies in four differing lower and middle income countries to tackle two challenges in respect of childhood cognitive development. First, it derived harmonized measures of cognitive performance and concurrently estimated the varying strengths of social and biological determinants of children's cognitive capacity via birthweight and early linear growth. Second, it applied structural equation modelling (SEM) suitable to outlining multiple pathways affecting cognitive development from variables in different development domains.

We tackled the first challenge methodologically and conceptually. Conceptually, we separated parental capacity and household resources, the educational and the economic capital available to children. They would have been run together as traditional socioeconomic status in the two-factor model. This distinction corresponds to the contrast drawn by Bourdieu (Bourdieu Halseyet al, 2009) between economic capital, "directly convertible to money" and cultural capital, i.e. attributes associated with the middle class such as reading and abstract language. The embodiment of cultural capital in the family, called "habitus", confers educational advantage on children through entrenched values and behaviours that encourage learning, including through exposure to books and reading, child-directed speech, encouragement and praise for cognitive gains, and educational aspirations (Gaddis, 2013). The concepts have been extensively used (Davies & Rizk, 2018) for example in a recent study of determinants of early cognitive scores in the United Kingdom (Sullivan et al., 2013). The factor scores for each these two constructs plus the third – birth endowment – were retained as exogenous variables together with maternal height, which was separated to observe its effects because of its prominence in our previous work (Richter et al., 2018).

Given the range of variables available to be included in the model, a key theoretical insight emerged both from the examination of the path coefficients from the exogenous variables to the outcome, children's cognitive capacity, and from the total of their direct and indirect effects on the outcome. The exogenous biological determinants (the birth order factor and maternal height) predominated over the social determinants (the household endowment and parental capacity factors) in their effects on birth weight. They were outweighed by the social determinants in their effects on height for age z at 24 months. Social determinants then strongly predominated over the biological in their effects on cognitive capacity.

Methodologically, we applied the exploratory version of SEM distinctive to Mplus. A specified number of predictive latent constructs are modelled in relation to the hypothesised model of mediators and outcome. Its novelty is that it explicitly recognises cross-loadings among the constructs rather than their being introduced as *ad hoc* retrospective adjustments. The resulting constructs are recognisable yet empirically nuanced, and facilitate plausible fit of complex models. In applying ESEM, the three-factor model was decisively better than the two-factor according to criteria of fit (RMSEA, CFI and TLI) and especially SRMR and BIC. This entailed the disaggregating of socio-economic status into social and cultural capital.

The sites provide sufficiently varying contexts to explore the relative effects of growth and social conditions on children's cognitive development. For instance, the generalisation that biological determinants of cognition may be stronger in poorer countries turns out, firstly, to be qualified by the strength of the social determinants, and secondly to be possibly less broadly applicable to boys in poor context than girls.

While the strengths of the analysis have been outlined, the study has several weaknesses.

The cognitive measures differed among the sites. However, they are each derived from well-accepted measures of childhood cognition and are used to rank children on measured cognitive functioning within each site in relation to the determinants assessed within the site. No assumption is made about the comparability of the levels of cognitive functioning or social variables across sites. To give an example, two years of schooling in Brazil may not be directly comparable to two years in Guatemala. But years of schooling is a valid measure of education of parents in both sites, as is its relation to measured cognitive functioning among children. While cultural capital is operationalised in this analysis by parental years of schooling, much is still to be learnt about how this indicator translates into day-to-day interactions between parents and children that enhance cognitive development.

Further, the assumptions of causality in the path model are based on observational data, but they are supported by the temporal succession of mediators and outcome. The analyses are limited by the small number of social variables measured in childhood that are shared among the cohorts, as well as missing data and limits on sample size in Brazil and Guatemala. Because of the complexity of the models, we assumed the relationships were linear. The negative coefficients from birth endowment to height at 2 years in the Philippines, to Cognitive Quotient from birth weight in Guatemala among males, and from height in Brazil among girls, may reflect non-linear effects. It is recommended that these are investigated in further analyses.

## Conclusions

Three main implications emanate from our analyses. Firstly, greater attention must be given to enhancing family capacity in efforts to improve children's developmental potential. To do that, we need better understanding of what aspects of cultural capital, here manifest in parental schooling, make the greatest difference to children's cognitive development. There are too few studies from low- and middle-income countries providing the level of detail needed to design interventions that can be delivered at scale (Richter et al., 2017). Also important are efforts to monitor child development in relation to improvements in both parental education and large-scale economic interventions to address poverty, such as cash transfers, as is being undertaken in Countdown to 2030's new emphasis on early childhood development (Richter et al., 2019).

Secondly, the findings suggest possible generalizability for planning interventions in terms of dynamic models of human development (Cunha & Heckman, 2007). For example, efforts to improve birth weight by addressing birth endowments, such as maternal nutrition and planning pregnancy, may be necessary but not sufficient to improve a subsequent phase of development, such as linear growth to 2 years. During this time, household resources adequate to support young children's growth and development become increasingly important. And they remain important for children's evolving cognitive functions. Again, though, these inputs are necessary but not sufficient for children's cognitive development. The latter also requires parental support for language development, imagination and motivation. No single intervention provides support required for young children's unfolding development over time.

Third, there are implications for the design of future studies to accommodate the increasing relative importance of social vis-à-vis biological factors as children advance through successive developmental milestones. The paper also points to the utility of techniques such as SEM and path analysis within it, as emphasised by Perkins et al. (2017), to capture the multiple interlinked pathways among different development domains, and from exogenous variables via mediators to outcome. In particular, the exploratory version of SEM indicated the importance of theoretically distinguishing, from among the ingredients traditionally baked into socio-economic status, between what we termed household resources and parental capacity: in Bourdieu's (Bourdieu Halseyet al, 2009) powerful conception, to distinguish between economic and cultural capital, with the latter here operationalised by parental education.

STROBE Statement—Checklist of items that should be included in reports of *cohort studies*.

| | Item No | Recommendation |
|---|---|---|
| **Title and abstract** | 1☑ | (*a*) Indicate the study's design with a commonly used term in the title or the abstract<br>(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found |
| Introduction | | |
| Background/ rationale | 2☑ | Explain the scientific background and rationale for the investigation being reported |
| Objectives | 3☑ | State specific objectives, including any prespecified hypotheses |
| Methods | | |
| Study design | 4☑ | Present key elements of study design early in the paper |
| Setting | 5☑ | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection |
| Participants | 6☑ | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up<br>(*b*) For matched studies, give matching criteria and number of exposed and unexposed |
| Variables | 7☑ | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable |
| Data sources/ measurement | 8☑ | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group |
| Bias | 9☑ | Describe any efforts to address potential sources of bias |
| Study size | 10☑ | Explain how the study size was arrived at |
| Quantitative variables | 11☑ | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why |
| Statistical methods | 12☑ | (*a*) Describe all statistical methods, including those used to control for confounding<br>(*b*) Describe any methods used to examine subgroups and interactions<br>(*c*) Explain how missing data were addressed<br>(*d*) If applicable, explain how loss to follow-up was addressed<br>(*e*) Describe any sensitivity analyses |
| Results | | |
| Participants | 13☑ | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed<br>(b) Give reasons for non-participation at each stage<br>(c) Consider use of a flow diagram |
| Descriptive data | 14☑ | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders<br>(b) Indicate number of participants with missing data for each variable of interest<br>(c) Summarise follow-up time (eg, average and total amount) |
| Outcome data | 15☑ | Report numbers of outcome events or summary measures over time |
| Main results | 16☑ | |

(*continued on next page*)

(*continued*)

| | Item No | Recommendation |
|---|---|---|
| | | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included<br>(*b*) Report category boundaries when continuous variables were categorized<br>(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period |
| Other analyses | 17☑ | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses |
| Discussion | | |
| Key results | 18☑ | Summarise key results with reference to study objectives |
| Limitations | 19☑ | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias |
| Interpretation | 20☑ | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence |
| Generalizability | 21☑ | Discuss the generalizability (external validity) of the study results |
| Other information | | |
| Funding | 22☑ | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based |

## Ethical statement

All field activities in each cohort were reviewed and approved by an appropriate ethics committee or Institutional Review Board and all participants (or their parents, as appropriate) provided informed consent for all measures reported.

## CRediT authorship contribution statement

**L.M. Richter:** designed the study, conducted the analysis and wrote the first full draft, All authors approved the submission. **F.M. Orkin:** designed the study, conducted the analysis and wrote the first full draft, All authors approved the submission. **L.S. Adair:** commented on the design, analysis and interpretation, helped to refine the manuscript, All authors approved the submission. **M.F. Kroker-Lobos:** All authors approved the submission. **N. Lee Mayol:** commented on the design, analysis and interpretation, helped to refine the manuscript, All authors approved the submission. **A.M.B. Menezes:** commented on the design, analysis and interpretation, helped to refine the manuscript, All authors approved the submission. **R. Martorell:** commented on the design, analysis and interpretation, helped to refine the manuscript, All authors approved the submission. **J. Murray:** commented on the design, analysis and interpretation, helped to refine the manuscript, All authors approved the submission. **A.D. Stein:** commented on the design, analysis and interpretation, helped to refine the manuscript, All authors approved the submission. **C. Victora:** commented on the design, analysis and interpretation, helped to refine the manuscrip.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2020.100648.

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