Do socio-economic inequalities in infant growth in rural India operate through maternal size and birth weight?

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Abstract

Background

3·1 million young children die every year from undernutrition. Greater understanding of associations between socio-economic status (SES) and the biological factors that shape undernutrition are required to target interventions.

Aim

To establish whether SES inequalities in undernutrition, proxied by infant size at 12 months, operate through maternal and early infant size measures.

Participants and Methods

The sample comprised 347 Indian infants born in 60 villages in rural Andhra Pradesh 2005-2007. Structural equation path models were applied to decompose the total relationship between SES (standard of living index) and length and weight for age Z-scores (LAZ/ WAZ) at 12 months into direct and indirect (operating through maternal BMI and height, birthweight Z-score and LAZ/WAZ at 6 months) paths.

Results

SES had a direct positive association with LAZ (Standardized coefficient = 0.08, 95% CI = 0.02, 0.13) and WAZ at age 12 months (Standardized coefficient = 0.08, 95%CI = 0.02, 0.15). It also had additional indirect positive associations through increased maternal height and subsequently increased birthweight and WAZ/LAZ at 6 months, accounting for 35% and 53% of the total effect for WAZ and LAZ respectively.

Conclusion

Findings support targeting evidence based growth interventions towards infants from the poorest families with the shortest mothers. Increasing SES can improve growth for two generations.

Introduction

High levels of undernutrition persist in low/middle income countries and especially in the poorest groups despite targeted global strategies (World Health Organization 2003; World Health Organization 2007). 3·1 million children younger than 5 years die every year from undernutrition (Horton and Lo 2013). Furthermore, child undernutrition (stunting, severe wasting, low birthweight, vitamin A and Zinc deficiencies and sub-optimal breastfeeding practices) linked to poverty contributes to approximately 35% of all child deaths due to leading causes such as measles, malaria, pneumonia, and diarrhoea worldwide (Black and others 2008). The first 1000 days (conception to 2 years) are established as critical to cognitive and physical development (Adair and others 2013; Grantham-McGregor, S., Cheung, Y. B., Cueto, S., Glewwe, P. and others 2007; Maternal and Child Nutrition Study group (2013).) Biological factors, such as nutrition of the mother during pregnancy, gestational age, birth weight, feeding practices, as well as socio-economic and demographic factors all shape this period (Katula and others 2014).

In 2014 India had a per capita gross domestic product of US$1631 (World Bank July 2015) and has seen reductions in unemployment and positive growth in its GDP by 6.2% between 1980-2010 (Varadharajan, Thomas, Kurpad 2013). Despite gains in per capita GDP, India houses 32.9% of the world's extreme poor living on less than $1.25 a day (United Nations. 2014) and still has the highest number of malnourished children of any country in the world, with 21% of infants born low birth weight (Bhat and Adhisivam 2013) and just under 50% of children under five years suffering from some form of undernutrition as evidenced by poor growth in weight or height relative to age compared to appropriate growth standards (Ramachandran 2007).

Failure to address issues such as poverty that limit the growth and development of infants and young children damage the development that all countries aspire to because of the vicious cycle between poverty and growth and development (Shonkoff and others 2012). A recent review of evidence has highlighted the importance globally of dealing with poverty as a barrier to implementing interventions targeted to achieve optimal infant and child nutrition (Dewey and Adu-Afarwuah 2014). Previous work has directly linked a failure to tackle infant and child undernutrition with hindering progress towards millennium development goals 1 (Eradicate extreme poverty and hunger), 2 (achieve universal primary education), and 4 (reduce child mortality) (Fotso and others 2012).

Poverty is associated with poor maternal size (Delpeuch and others 2000; Shell-Duncan and Yung 2004) and lower body mass indices in women of reproductive ages (Griffiths and Bentley 2001). In reviews of studies from different locations, poor maternal nutritional status as measured by an underweight body mass index (BMI) (Han and others 2011) or short maternal stature (Martorell and Zongrone 2012) have been strongly associated with low birthweight. Poor maternal nutritional status as measured by a shorter height or a low pre-pregnancy weight has also been associated with low birthweight in the Indian context (Deodhar and Jarad 1999; Mumbare and others 2012). Mothers who are stunted will have experienced chronic under-nutrition in early life, primarily before 5 years of age (Stein and others 2010). Associations between poor infant size outcomes and low maternal height highlight inter-generational transmission of poor growth outcomes. Given the strong link between early growth and poverty, these associations also provide a good indication of inter-generational transmission of poverty (Martorell and Zongrone 2012). Maternal size as measured by height or BMI is also associated with infant growth beyond birth with significant relationships being observed with both weight and height across different regions (Casapía and others 2007) including India (Subramanian and others 2009; Subramanian, Ackerson, Smith 2010).

Relatively low socio-economic status at the individual and neighbourhood level has also been clearly linked in review papers to low birth weight across a range of geographic settings (Blumenshine and others 2010; Weightman and others 2012), including India (Kader and Perera 2014; Mumbare and others 2012). Low birthweight is also significantly associated with poor infant growth (Gutbrod and others 2000; Ye and others 2010), although low birthweight infants often experience catch-up growth if postnatal conditions are optimal, which can improve early health outcomes by reducing morbidity and mortality (Victora and others 2001). Although there are potential early health gains from catch-up growth, this pattern of rapid growth is also widely associated with greater risk of non-communicable diseases in adulthood through increased risk of obesity, higher adult fat mass (especially visceral fat) and increased risk factors for type 2 diabetes and cardiovascular disease (Jain and Singhal 2012; Nobili and others 2008).

Human Biologists can contribute to growing knowledge in this area by providing more detailed information on the extent to which poverty’s effects on infant and child growth are mediated by biological factors such as maternal size and fetal growth. Such information is needed to develop and effectively target interventions aimed at breaking the cycle between poverty and infant and child under nutrition. For example would interventions targeted in adolescence at improving maternal height or those targeted directly towards infant growth pre or post natally have the greatest potential to reduce SES inequalities in under nutrition in the first 12 months of life? What kind of effect can such interventions be expected to have overall on infant growth and narrowing SES inequalities?

Much of the literature linking poverty and poor infant growth outcomes has modelled direct (total) paths between socio-economic status and infant anthropometric outcomes using multiple regression modelling techniques, while controlling for potentially mediating biological factors like birthweight and/or maternal size. This approach allows the effect of socio-economic status on the anthropometric outcome to be established independent of any associated correlation with birthweight and/or maternal size. However, a single regression model does not allow for the simultaneous identification of both direct and indirect paths (eg through maternal size and infant birthweight) through which socio-economic status might operate to be associated with infant anthropometric outcomes at 12 months. Identifying biological pathways through which poverty works to influence infant size is important to more appropriately target interventions to reduce the cycle of poverty and malnutrition in infants. In comparison to multivariable regression modelling techniques, structural equation path models allow a more in depth assessment of both the direct and indirect biological paths through which socio-economic status may operate to influence anthropometric outcomes at 12 months. SEM path modelling goes beyond simple multiple linear regression which explores relationships among explanatory and response variables to provide an environment for a more interpretive structure because it uses simultaneous regression models allowing for interdependencies between variables and hypotheses to be modelled (Grace and Bollen 2005). For instance using SEM path models to study socio-economic status and infant size at 12 months, it is possible to look at the direct and indirect effects (through maternal size and early infant size) of socio-economic status on infant size at 12 months simultaneously.

The aim of this paper is to establish whether socio-economic inequalities in infant size at 12 months in rural India operate through maternal and infant size measures using a structural equation path analysis to disaggregate direct and indirect paths.

Participants and Methods

Participants come from an Indo-US funded collaborative longitudinal study, hereafter called the Infant Feeding Study (IFS), of the 'efficacy of an integrated feeding and care intervention among 3 to 16 month old rural infants in India' (Vazir and others 2013). The original study was designed to test an infant feeding and care for development intervention across two intervention groups and compare these to a control group. The IFS recruited all infants born across three Integrated Child Development Scheme (ICDS) project areas covering 60 rural villages at 2 to 3 months of age in the rural Nalgonda district of Andhra Pradesh, between September 2005 and April 2007, providing a total sample of 600 recruited infants, of which 511 were followed for 12 months. In this analysis we exclude 62 pre-term births and use data from 347 participants (48% female). We focus the analysis on those who survived (6 infants died) without disabilities (6 had developmental delay problems) with complete socio-economic data (62 infants did not have socio-economic data recorded), with complete maternal and infant size data at birth, 6 and 12 months (15 additional cases lacked complete anthropometric data), and information at 6 and 12 months to calculate the exact age at assessment (13 lacked exact age data). Comparisons were made between the analysis sample and the sample followed for 12 months (n=511) for gender and intervention group (these variables had complete data) using Chi-Square tests and no statistically significant differences ($P > 0.05$) were observed. Comparisons were also made between the analysis sample and available data for the remaining sample for standard of living index and maternal height, and BMI using independent samples t-tests and no statistically significant differences were observed between those included in the final analysis and those excluded from the original 511.

Data

Weight and length were measured monthly using standard techniques (Cameron 1984) between three and 12 months of age. *Z*-scores for weight and length were calculated using the WHO (2006) standard data (WHO Anthro 3.1) at birth (weight only), 6 months and 12 months of age (WHO Multicentre Growth Reference Study Group). Birthweight and gestational age were obtained from birth records and maternal measures of weight and height were assessed during recruitment. Maternal body mass index ($BMI=kg/m^2$) was calculated.

Project technical staff administered questionnaires to IFS mothers to assess maternal characteristics, including age, parity of the infant and a Standard of Living Index (SLI). The SLI is based on the index created by the National Family Health Survey of India 2 (International Institute for Population Sciences (IIPS) and Macro International 2000), which is an index of consumer durables, housing type, facilities available to the household, cooking space and facilities and ownership of housing, livestock and land that gives the relative level of socioeconomic status of a household to the national average in the absence of income or wealth data. This standard of living index was further standardized within the study sample by creating internal Z-scores (mean = 26.77, SD = 7.94) as the original index had been calculated relative to a national average.

The study was approved by the Institutional Ethics Committee of the National Institute of Nutrition, ICMR, Hyderabad, India and the Institutional Review Board of the University of North Carolina, Chapel Hill, USA.

Statistical Analysis

Descriptive statistics for infant characteristics including sex and size as well as maternal BMI, and the Z-score for the household standard of living index were produced. Correlation coefficients between all variables were calculated to help inform the structural equation modelling process.

To model the direct paths between socio-economic status (based on the standard of living index) and infant size at 12 months (assessed using weight for age and height for age Z-scores) as well as the indirect paths (through infant birthweight, maternal BMI, maternal height and infant size at 6 months (assessed using weight for age and height for age Z-scores) a structural equation path modelling (SEM) approach was used with maximum likelihood estimation (See Figure 1). The model paths were drawn based on the evidence from existing literature of potential paths that might exist (e.g. Evidence exists in the literature for a path between maternal size and infant anthropometric outcomes (Subramanian and others 2009; Subramanian, Ackerson, Smith 2010)).

Models reported in the paper include only the paths that included the standard of living index or those that retained statistical significance ($P < 0.05$). These models are presented to facilitate the most parsimonious analyses. As it was possible that anthropometric outcomes at 12 months would vary between intervention groups from the original study, an intervention variable was added as a competing effect into the final models by creating a direct path from intervention group to the infant anthropometric outcome at 12 months. This was to eliminate the possibility that the intervention effect had a significant influence on the size of the infant at 12 months observed in these Indian infants compared to a population without intervention. There was no significant effect of intervention (complimentary nutrition education vs control; complementary nutrition education plus care intervention vs control) on weight or length at 12 months or the paths between socio-economic status and these outcomes, meaning the intervention variable was not retained in the models. Age of the mother (5 year age groups) and parity of the birth (1,2 or 3 plus) were also added into final models but their effects were found to be insignificant and they did not affect the significance of any of the socio-economic status paths being tested. They were therefore not retained in final model results presented.

Model fit for structural equation models can be assessed with a range of indices. Here we use the convention reported by Schreiber et al. (2006) that studies should use a range of fit indices and that “if the vast majority of the indexes indicate a good fit, then there is probably a good fit” (Schreiber and others 2006: 327). We present the Root Mean Square Error of Approximation (RMSEA), the comparative fit index (CFI), and standardised root mean square residual (SRMR). For a good fit, the RMSEA should be less than 0.06-0.08 with its 90% confidence interval, the CFI should be greater than or equal to 0.95 and the SRMR less than or equal to 0.08 (Schreiber and others 2006). Model estimates are presented as both standardised and unstandardized coefficients. The standardised coefficients allow the relative size of effects of different variables and paths in the model to be easily compared. This is more difficult with the unstandardized coefficients because of the different units of measurement of the different variables included into the model (Grace and Bollen 2005). However, there are also limitations of standardized coefficients including variation in variance estimates between different samples (as standardized coefficients are based on standard deviation values) making study comparisons more difficult (Grace and Bollen 2005). We therefore include both standardised and unstandardized estimates in the results section.

In order to quantify the effects of poverty on the infant anthropometric outcomes at 12 months in this sample a comparison is made, based on model coefficients, to compare the anthropometric status of an infant coming from a household with a standard of living assessed at the 2.5th percentile of the distribution (to represent a household living in poverty) to an infant residing in a household at the 97.5th percentile of the standard of living distribution (to represent a relatively wealthy household). Households at the 2.5th percentile of the distribution are 1.96 standard deviations below the mean, whilst those at the 97.5th percentile are 1.96 standard deviations above the mean. The parameter estimates for the combined indirect and direct effect of socio-economic status on length or weight are therefore multiplied by

3.92 to establish the difference between a relatively poor and wealthy infant in the sample that could be associated with socio-economic status, holding other coefficients at their mean value.

Descriptive statistics were calculated using SPSS version 22 (Chicago, IL) and structural equation models were produced using STATA SE version 13 (College Station, TX).

Results

Descriptive Statistics

Descriptive statistics (Table 1) show the infants in this sample to be below the WHO (2006) standard values (WHO Multicentre Growth Reference Study Group) on average for weight and height from birth to 12 months and that the sample is further below the reference values at 12 months than at younger ages. Mothers in the sample also have low BMI values on average (mean = 19.83) and are short (mean = 151.48 cms). Compared to the NFHS2 national standard of living index scores, 4% of the sample is considered low SES, 37% medium and 59% high. Statistically significant correlations were observed between the standard of living index and maternal height and infant size at 6 and 12 months of age. The standard of living index did not show a significant correlation with birthweight or maternal BMI. Furthermore the correlation coefficients reveal that a problem of multicolinearity is unlikely, because correlation coefficients are all below 0.85.

Model Fit

In both SEM models requirements for appropriate fit (see methods) are met when judged by the Chi-Square, CFI and SRMR (Table 3). For height the fit is also good based on the RMSEA. For weight the upper bound of the 90% confidence interval is slightly higher than the recommended 0.08 at 0.12. However, the model fit diagnostics are mostly satisfied. To improve model fit insignificant SLI paths in the model were removed (results not shown). This resulted in all model fit statistics showing a good fit, but did not alter the conclusions that would be reached from other paths shown in the model. We therefore present consistent models for weight and height in this paper and leave all SLI paths in the models tested.

Length for Age at 12 months

The structural equation model (Figure 1 and Table 4) reveals a combined direct and indirect (total) effect of a 0.17 standard deviation increase in LAZ at 12 months associated with a one standard deviation increase in standard of living. The standard of living index has a direct association with length for age (LAZ) at 12 months (Standardized coefficient = 0.08, 95% CI = 0.02, 0.13, P=0.006) indicating that a one standard deviation increase in the standard of living index is directly associated with a 0.08 standard deviation increase in LAZ.

The structural equation model also enables understanding of the indirect paths through which the standard of living index is associated with LAZ at 12 months. The size of the standardised coefficient for an indirect path is calculated by taking the product of the standardised coefficients on the pathway between the standard of living index and the LAZ at 12 months. For example for the indirect path between the standard of living index and maternal height and LAZ at 12 months we take the standardised coefficient for the path between the standard of living index and maternal height (0.19 from Figure 1) and multiply it by the standardised coefficient from the path from maternal height to LAZ at 12 months (0.08 from Figure 1). The result is 0.02, which means that the standard of living index is associated with an indirect effect of a 0.02 standard deviation increase in LAZ at 12 months through maternal height. It is possible to further deconstruct this association to look at the indirect pathway from the standard of living index to maternal height through LAZ at 6 months to LAZ at 12 months (0.19*0.38*0.80). This shows that a one standard deviation increase in the standard of living index is associated with a 0.06 standard deviation increase in LAZ at 12 months through this indirect path. The indirect pathways from the standard of living to maternal height through birthweight and LAZ at 6 months to LAZ at 12 months (0.19*0.20*0.33*0.80) shows that a one standard deviation increase in SLI is associated with a 0.01 standard deviation increase in LAZ at 12 months. This results in a total indirect effect of socio-economic status through height that equates to a 0.09 standard deviation increase in LAZ for every standard deviation increase in SLI. This is equivalent to 53% of the total socio-economic effect.

Indirect paths from standard of living through birthweight, LAZ at 6 months and maternal BMI to LAZ at 12 months were not statistically significant. Other indirect paths with more than one variable on the direct path from standard of living to LAZ at 12 months produced estimates less than 0.01.

Results reveal that moving from the 2.5th percentile for the standard of living index to the 97.5th percentile in this rural Indian population has the potential to improve LAZ at 12 months by (0.17*3.92) 0.67 Z-scores.

Weight for Age at 12 months

Results for weight for age (Figure 1 and Table 5) reveal a combined direct and indirect (total) effect of a 0.20 standard deviation increase in the weight for age Z-score (WAZ) at 12 months associated with a one standard deviation increase in standard of living. The structural equation model reveals that the standard of living index has a direct effect on WAZ at 12 months (Standardized coefficient = 0.08, 95%CI = 0.02, 0.15, P-value = 0.008) indicating that a one standard deviation increase in the standard of living index is directly associated with a 0.08 standard deviation increase in WAZ.

The standard of living index also has a significant indirect path through maternal height (0.18* (-)0.02 = - 0.004) and a borderline significant (p=0.057) indirect path through WAZ at 6 months (0.09*0.82=0.07) associated with WAZ at 12 months. The indirect path between standard of living and WAZ at 6 months to WAZ at 12 months accounts for 35% of the total effect of socio-economic status on WAZ at 12 months. Although the indirect path through maternal height directly to WAZ at 12 months has a small effect because maternal height is not directly significantly associated with WAZ at 12 months, the effect of standard of living on maternal height and early infant weight is larger. The indirect path from standard of living through maternal height and infant WAZ at 6 months (0.18*0.24*0.82) shows that a one standard deviation increase in the standard of living would be associated with a 0.04 standard deviation increase in WAZ through this indirect path. Furthermore the indirect path from standard of living through maternal height, infant birthweight and infant WAZ at 6 months to WAZ at 12 months (0.18*0.20*0.37*0.82) is associated with a 0.01 standard deviation increase in WAZ. This results in a total indirect effect of socio-economic status through height that equates to a 0.05 standard deviation increase in WAZ for every standard deviation increase in SLI, which is 25% of the total socio-economic effect.

Indirect paths from standard of living through birthweight and maternal BMI to WAZ at 12 months were not statistically significant. Other indirect paths with more than one variable on the direct path from standard of living to WAZ at 12 months produced estimates less than 0.01.

Results reveal that moving from the 2.5th percentile for the standard of living index to the 97.5th percentile in this rural Indian population has the potential to improve WAZ at 12 months by (0.20*3.92) 0.78 Z-scores.

Discussion

Findings show that socio-economic status has significant direct and indirect associations with WAZ and LAZ, with direct associations accounting for 47% of the total effect for LAZ and 40% for WAZ at 12 months. Significant indirect pathways explain the majority of the total socio-economic effect on infant anthropometric outcomes at 12 months and have been identified to be maternal height and WAZ at 6 months (WAZ only). Maternal height was not significantly associated with WAZ at 12 months after the effect of maternal height on WAZ at 6 months was modelled.

This means that the indirect effect of socio-economic status through maternal height on infant weight is most significant for infant growth in weight to 6 months. For LAZ socio-economic status was associated with maternal height and this was significantly associated with LAZ at 12 months. This means that the indirect effect of socio-economic status through maternal height is significant for infant growth in height at least to 12 months of age in this rural South Indian sample. These findings add further weight to the call from previous studies to tackle poverty in the long term to reduce the prevalence of under nutrition in infants and break the cycle between poverty and malnutrition (Black and others 2008; Shonkoff and others 2012).

The use of SEM path models has enabled identification of maternal height as an important indirect path in the association between socio-economic status and infant size at 12 months. Previous work has linked socio-economic status to maternal size (Delpeuch and others 2000; Shell-Duncan and Yung 2004) and maternal size to infant size in the first year of life (Deodhar and Jarad 1999; Han and others 2011; Martorell and Zongrone 2012; Mumbare and others 2012). The findings from the SEM approach used here allow the simultaneous modelling of these relationships, which reveals that as well as the direct socio-economic association with infant anthropometrics at 12 months, there is an indirect effect of socio-economic status on maternal height that works through birthweight and infant size at 6 months to associate with anthropometric outcomes at 12 months. Lower SES is associated with shorter maternal stature, which in turn is related to lower birthweight and anthropometric outcomes in infancy. These indirect effects account for 53% of the total effect of socio-economic status on LAZ at 12 months and 25% of the total effect of socio-economic status on WAZ at 12 months, showing lasting inter-generational maternal height effects of poverty on infant size. A difference in the findings between LAZ and WAZ for the indirect associations with socio-economic status and maternal height was that maternal height was directly associated with LAZ at 12 months but not WAZ at 12 months, although maternal height was associated with WAZ at 6 months. This suggests the socio-economic effects through maternal height have longer lasting associations with infant growth in height than weight. Height has a very strong genetic component, which would explain the continued direct association with maternal height to 12 months (Towne, Demerath, Czerwinski 2012). Weight is more sensitive to the environment and over time the impact of environmental factors likely becomes greater than the effects of uterine capacity and genetic factors related to maternal stature (Towne, Demerath, Czerwinski 2012).

Although results show an indirect path between socio-economic status, maternal height and infant anthropometric outcomes, no similar significant relationship has been identified between socio-economic status and maternal body mass index. Other studies do observe a significant association between socio-economic status and maternal body mass index when this relationship is studied in isolation (Delpeuch and others 2000; Griffiths and Bentley 2001; Shell-Duncan and Yung 2004). Although no significant relationship between socio-economic status and maternal body mass index is observed, results do reveal a significant direct relationship between maternal body mass index and infant anthropometric outcomes at 12 months, which is consistent with previous work (Casapía and others 2007; Subramanian, Ackerson, Smith 2010). The lack of a relationship between socio-economic status and body mass index could be related to the simultaneous modelling of other biological pathways including maternal height. However, this is unlikely as no significant association was identified between socio-economic status and maternal body mass index in the correlation matrix before controlling for other factors. Another explanation for the lack of association could be related to the assessment of maternal weight at baseline (approximately 3 months post-partum) in this study (see limitations section).

Findings also do not show a direct significant relationship between socio-economic status and birthweight, which is different to the consensus on this relationship from published review evidence (Blumenshine and others 2010; Weightman and others 2012). Although a direct association was not observed, the SEM models do identify an indirect significant association between socio-economic status, maternal height and birthweight. This indirect pathway is significantly linked to anthropometric outcomes at 12 months through the significant associations between birthweight and infant anthropometric outcomes at 6 and 12 months and accounts for 6% of the total effect of the association between socio-economic status and infant LAZ at 12 months and 5% of the total effect for infant WAZ at 12 months. This allows us to show that the socio-economic association with birthweight to later infant anthropometric outcomes in this sample is wholly explained by those from relatively poorer households within the sample having mothers with shorter stature, who in turn have significantly lower birthweight babies. We therefore add to the weight of evidence relating to the importance of interventions that work to improve growth in height of females for improving birthweight (Deodhar and Jarad 1999; Martorell and Zongrone 2012; Mumbare and others 2012) and subsequent infant growth (Subramanian and others 2009) and furthermore show that such interventions will have the greatest effect when targeted at the poorest households.

What do our findings mean for future research/ policy?

Taken together findings from this research show that focusing on families with low socio-economic status and a mother with a shorter stature would target the most vulnerable families to improve growth and assist in breaking the cycle of malnutrition and poverty. Results suggest that the relative effect of poverty in this sample when moving from a household with a standard of living on the 2.5th percentile versus the 97.5th percentile would be associated with a 0.67 SD improvement in LAZ at 12 months and 0.78 SDs for WAZ when both the direct and indirect effects of socio-economic status through maternal height and infant size at 6 months are considered. Clinically significant catch-up or rapid growth in the first two years has been defined as 0.67 SDs because this equates to the width of each percentile band on growth charts e.g. crossing from the 9th to 25th percentile (Ong and others 2000). This means that the effect of moving from the low end of the SES scale to the high end is equivalent to greater than clinically significant rapid or catch-up growth in weight and clinically significant catch up growth for length. Results reveal that opportunities to improve weight based on these target parameters are greatest in the first 6 months. For height this opportunity extends to at least 12 months based on the evidence presented here although the effect sizes are greatest through the indirect path from maternal stature to anthropometric outcomes at 6 months and subsequently 12 months showing the importance of maternal stature in poorer families for very early infant growth.

Strengths and limitations

This analysis is focused on a rural population in one area of one state of India, which limits heterogeneity in socio-economic status. Nevertheless the standard deviation for the standard of living index shows that there is some heterogeneity in socio-economic status in this population and we do observe significant direct and indirect effects of the standard of living index in a relatively homogeneous population. It is possible that the effect would be even greater in a more heterogeneous sample. These findings do make it possible to conclude that even in one rural area it is possible to see reductions in inequalities in infant growth by improving socio-economic status, especially in households with mothers with relatively short stature.

This study also lacks a variety of socio-economic indicators including income and expenditure data, which are considered the most robust measures of socio-economic status, although such measures are expensive to collect and have limitations especially in poorer communities (Barrett, Carter, Little 2006; May and Roberts 2001). This study relies on a proxy measure of wealth to assess socio-economic status. Previous research has shown that such proxy measures can be reasonable estimates of wealth in the absence of income and expenditure data (Filmer and Pritchett 2001).

Birthweight was not directly observed in this study because baseline recruitment did not commence until approximately 3 months post-partum because many mothers leave their own home to deliver in their natal homes in this setting, making tracking of mothers for birth assessments difficult. This means that the birthweight data come from records on health cards, which were not subject to the same robust measurement protocols used for later anthropometric assessments in this study.

This likely introduces error into the birthweight measure included in models and may affect associations observed with socio-economic status, especially if error is correlated with household socio-economic status.

Maternal weight was assessed at baseline (approximately 3 months post-partum) in this study, which means that weight was likely influenced by lactation and recent pregnancy and this introduces error. This error will also be included in body mass index calculations and may partly explain the lack of association between socio-economic status and body mass index in this study compared to previous work. This study also lacks information on weight gain during pregnancy, which would have been a useful addition to include into the path model in order to understand the relationship between socio-economic position and infant growth in the first year.

A fully adjusted model would also consider the village (cluster) level effect. In this paper our aim was to establish whether socio-economic inequalities in infant size at 12 months in rural India operate through maternal and infant size measures, meaning that using a structural equation path approach to the modelling was central to the testing of this aim because it allows for testing of pathways. The proper modelling of village requires a multilevel approach, with the inclusion of a random intercept term for village. Using a structural equation path approach and not a multilevel approach would likely have little effect on the coefficient estimates presented. However, adjustment for cluster in a multilevel framework would improve the confidence interval estimates for the parameters because standard error estimates would be more robustly estimated (Raudenbush and Bryk, 2002).

The strength of this study is the range of maternal and infant size measures collected during the first year of life as well as the availability of a multidimensional measure of socio-economic status. This alongside the application of the SEM path model framework to the data have produced findings that help to establish socio-economic inequalities in infant growth in rural India and identify direct and indirect pathways through maternal and early infant size measures from socio-economic status to infant anthropometric outcomes at 12 months.

Conclusion

Findings show socio-economic inequalities in infant growth in rural India partially operate through maternal height and to a lesser extent birth weight through its relationship with maternal height. Because higher standard of living was related to greater maternal stature and in turn greater infant size, improvements in standard of living have the potential to improve growth in two generations. Evidence from this study suggests that targeting evidence based nutrition and growth interventions (Bhutta et al., 2013 provides a review of evidence based nutrition specific interventions and Ruel et al., 2013 a review of evidence based nutrition sensitive interventions (Bhutta and others 2013; Ruel, Alderman, Maternal and Child Nutrition Study Group. 2013)) towards infants from the most vulnerable poor families with the shortest mothers would have the greatest potential for breaking the cycle between poverty and malnutrition in infancy in rural South India.

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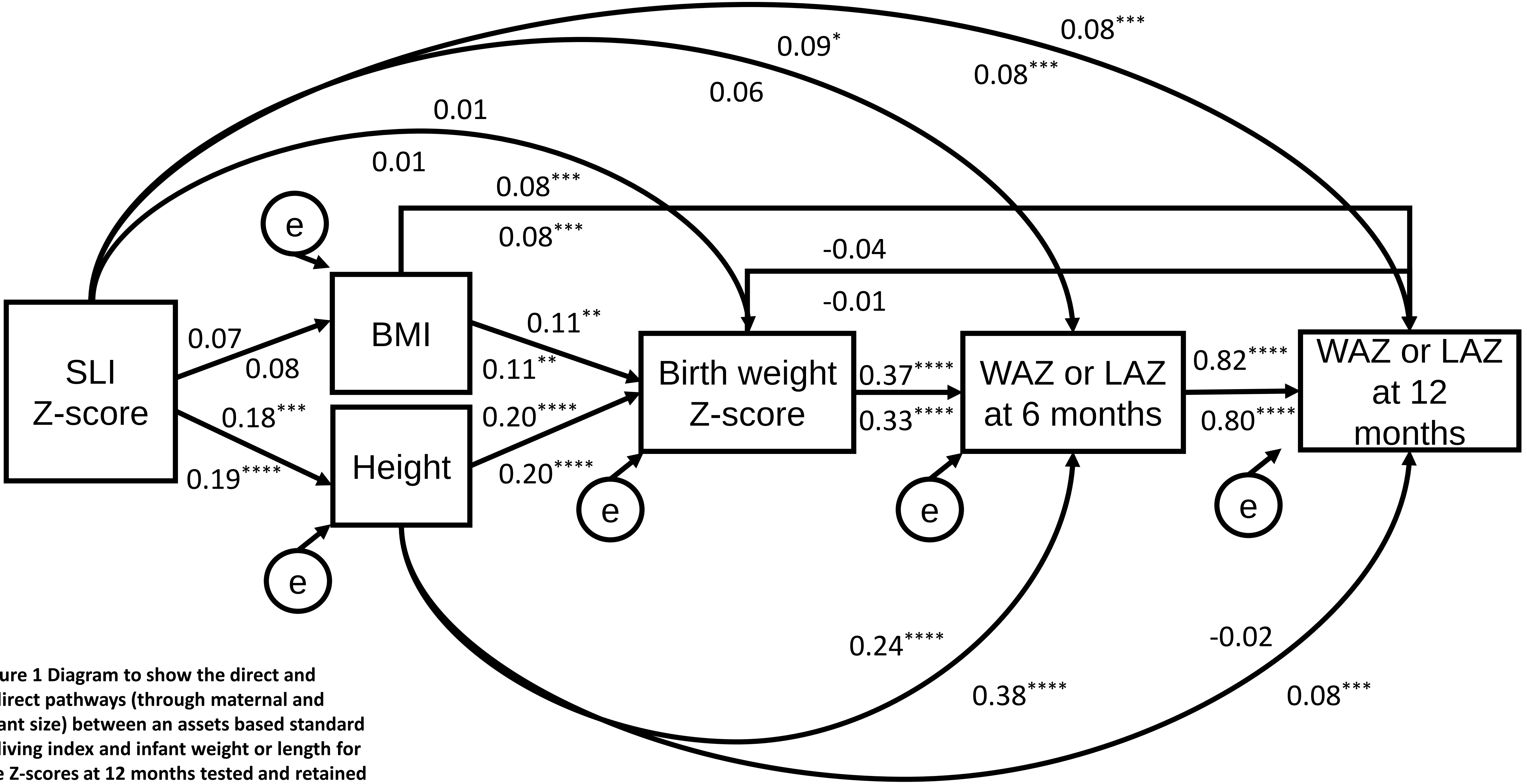

Figure 1 Diagram to show the direct and indirect pathways (through maternal and infant size) between an assets based standard of living index and infant weight or length for age Z-scores at 12 months tested and retained in the structural equation models as well as standardised regression coefficients for pathways (estimates below the line are for LAZ and above are for WAZ)

* P-value < 0.10 and >0.05, ** P-value < 0.05 and > 0.01, *** P-value < 0.01 and > 0.001, **** P-value < 0.001

Table 1 Rural South Indian sample descriptive statistics relating to infant and maternal size, and standard of living index

Variable	n		
Infant characteristics			
Male	180	%	51.9
Female	167	%	48.1
Birthweight z-score	347	Mean (SD)	-1.06 (1.12)
Weight for age Z-score 6 months	347	Mean (SD)	-1.00 (1.05)
Length for age Z-score 6 months	347	Mean (SD)	-1.16 (0.95)
Weight for age Z-score 12 months	347	Mean (SD)	-1.29 (1.01)
Length for age Z-score 12 months	347	Mean (SD)	-1.52 (0.96)
Maternal characteristics			
Body mass index	347	Mean (SD)	19.83 (2.66)
Height (cms)	347	Mean (SD)	151.48 (5.48)
Household characteristics			
Standard of living index (raw score)	347	Mean (SD)	26.95 (8.05)

Table 2 Correlation coefficients for the variables tested in the structural equation model for this rural South Indian sample

	Weight for age Z-score 12 months	Length for age Z-score 12 months	Weight for age Z-score 6 months	Length for age Z-score 6 months	Birthweight Z-score	Maternal height	Maternal BMI
Weight for age Z-score 12 months							
Length for age Z-score 12 months	0.697 (P<0.001)						
Weight for age Z-score 6 months	0.812 (P<0.001)	0.654 (P<0.001)					
Length for age Z-score 6 months	0.629 (P<0.001)	0.860 (P<0.001)	0.687 (P<0.001)				
Birthweight Z-score	0.311 (P<0.001)	0.342 (P<0.001)	0.421 (P<0.001)	0.404 (P<0.001)			
Maternal height	0.254 (P<0.001)	0.443 (P<0.001)	0.331 (P<0.001)	0.449 (P<0.001)	0.204 (P<0.001)		
Maternal BMI	0.193 (P<0.001)	0.111 (P=0.038)	0.133 (P=0.013)	0.053 (P=0.323)	0.114 (P=0.033)	0.007 (P=0.891)	
Standard of living Z-score	0.209 (P<0.001)	0.213 (P<0.001)	0.155 (P=0.004)	0.147 (P=0.006)	0.055 (p=0.305)	0.187 (P<0.001)	0.074 (P=0.169)

Table 3 Model fit statistics for length for age and weight for age Z-score outcomes for the rural South Indian sample

	Weight for age model	**Length for age model**
Chi-square model vs. saturated	**3.21 (P=0.201)**	**0.034 (P = 0.983)**
RMSEA	**0.04 (90%CI 0.00, 0.12)**	**0.00 (90%CI 0.00, 0.03)**
Comparative Fit Index	**0.998**	**1.00**
Standardized root mean squared residual	**0.020**	**0.002**
Coefficient of determination	**0.07**	**0.07**

Table 4 Unstandardized coefficients from a structural equation model of direct and indirect pathways (through maternal and infant size) between a standard of living index and infant length for age Z-scores at 12 months

Variable and pathway	Unstandardised Coefficient (se)	95% CI	P-value
Length for age Z-score 12 months ←[1]			
Maternal height	**0.01 (0.01)**	**0.003, 0.02**	**0.015**
Maternal body mass index	**0.03 (0.01)**	**0.009, 0.05**	**0.005**
Birthweight Z-score	**-0.01 (0.03)**	**-0.058, 0.05**	**0.858**
Length for age Z-score 6 months	**0.82 (0.03)**	**0.749, 0.88**	**<0.001**
Z-score standard of living index	**0.08 (0.03)**	**0.022, 0.13**	**0.006**
Constant	**-3.10 (0.90)**	**-4.875, -1.33**	**0.001**
Error (Variance) Length for age Z-score 12 months	**0.26 (0.02)**		
Maternal height ←			
Z-score standard of living index	**1.01 (0.29)**	**0.446, 1.56**	**<0.001**
Constant	**151.48 (0.29)**	**150.91, 152.04**	**<0.001**
Error Maternal height	**28.93 (2.20)**		
Maternal body mass index ←			
Z-score standard of living index	**0.20 (0.14)**	**-0.077, 0.47**	**0.158**
Constant	**19.82 (0.14)**	**19.540, 20.09**	**<0.001**
Error (Variance) Maternal Body Mass Index	**6.99 (0.53)**		
Birthweight Z-score ←			
Maternal height	**0.04 (0.01)**	**0.019, 0.06**	**<0.001**
Maternal body mass index	**0.05 (0.02)**	**0.003, 0.09**	**0.038**
Z-score standard of living index	**0.01 (0.06)**	**-0.104, 0.13**	**0.853**
Constant	**-8.20 (1.71)**	**-11.54, -4.85**	**<0.001**
Error (Variance) Birthweight Z-score	**1.18 (0.09)**		
Length for age Z-score 6 months ←			
Maternal height	**0.07 (0.01)**	**0.050, 0.08**	**<0.001**
Birthweight Z-score	**0.28 (0.04)**	**0.20, 0.35**	**<0.001**
Z-score standard of living index	**0.06 (0.04)**	**-0.03, 0.14**	**0.179**
Constant	**-10.80 (1.23)**	**-13.21, -8.38**	**<0.001**
Error (Variance) Length for age Z-score 6 months	**0.62 (0.05)**		

[1] A variable label in bold in the table with an ← after the label is depicting the pathway associations being shown with the non bolded variables listed below it e.g. Length for age Z-score 12 months ← is followed by parameter estimates depicting association with this outcome for maternal height, body mass index, infant birth weight, length for age at 6 months and Z-score standard of living index. Pathways relate to the overall model tested in Figure 1.

Table 5 Unstandardized coefficients from a structural equation model of direct and indirect pathways (through maternal and infant size) between a standard of living index and infant weight for age Z-scores at 12 months

Variable and pathway	Unstandardized coefficient (se)	95% CI	P-value
Weight for age Z-score 12 months ←[1]			
Maternal height	**-0.004 (0.01)**	**-0.02, 0.01**	**0.489**
Maternal body mass index	**0.03 (0.01)**	**0.01, 0.05**	**0.007**
Birthweight Z-score	**-0.04 (0.03)**	**-0.10, 0.02**	**0.239**
Weight for age Z-score 6 months	**0.79 (0.03)**	**0.72, 0.85**	**<0.001**
Z-score standard of living index	**0.08 (0.03)**	**0.02, 0.14**	**0.008**
Constant	**-0.54 (0.97)**	**-2.44, 1.37**	**0.582**
Error (Variance) Weight for age Z-score 12 months	**0.33 (0.03)**		
Maternal height ←			
Z-score standard of living index	**1.01 (0.28)**	**0.45, 1.57**	**<0.001**
Constant	**151.46 (0.29)**	**150.89, 152.02**	**<0.001**
Error (Variance) Maternal height	**28.83 (2.19)**		
Maternal body mass index ←			
Z-score standard of living index	**0.19 (0.14)**	**-0.08, 0.47**	**0.167**
Constant	**19.82 (0.14)**	**19.55, 20.10**	**<0.001**
Error (Variance) Maternal Body Mass Index	**7.00 (0.53)**		
Birthweight Z-score ←			
Maternal height	**0.04 (0.01)**	**0.02, 0.06**	**<0.001**
Maternal body mass index	**0.05 (0.02)**	**0.004, 0.09**	**0.032**
Z-score standard of living index	**0.01 (0.06)**	**-0.11, 0.12**	**0.862**
Constant	**-8.20 (1.70)**	**-11.54, -4.87**	**<0.001**
Error (Variance) Birthweight Z-score	**1.17 (0.09)**		
Length for age Z-score 6 months ←			
Maternal height	**0.04 (0.01)**	**0.03, 0.06**	**<0.001**
Birthweight Z-score	**0.34 (0.05)**	**0.26, 0.43**	**<0.001**
Z-score standard of living index	**0.09 (0.05)**	**-0.002, 0.20**	**0.057**
Constant	**-7.56 (1.41)**	**-10.32, -4.80**	**<0.001**
Error (Variance) Weight for age Z-score 6 months	**0.82 (0.06)**		

[1] A variable label in bold in the table with an ← after the label is depicting the pathway associations being shown with the non bolded variables listed below it e.g. Weight for age Z-score 12 months ← is followed by parameter estimates depicting association with this outcome for maternal height, body mass index, infant birth weight, weight for age at 6 months and Z-score standard of living index. Pathways relate to the overall model tested in Figure 1.